The Earthworm Book

Sultan Ahmed Ismail

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by Sultan Ahmed Ismail

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For my wife
Tasneem
whose understanding silence enabled me
to complete this book

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Preface

For several hundred years the earthworm was known only in text-books but it has now become a household name with its role redefined from 'farmer's friend' to 'solid waste manager'.

The material in this book has been compiled in order to enable to the reader to derive information about earthworms, and to realise what these creatures are, understand their contribution to agriculture, learn how they can be cultured and how they can also be used in solid waste management. The style used in this book is simple and direct. It is written for anyone interested in earthworms and vermicology – the farmer, the agriculturist, the student of applied zoology, the vermiculturist, the researcher and even any layperson at home.

The large quantity of literature on the biology and ecology of earthworms makes it impossible to keep up with everything that has been written about these creatures. To a large extent, the emphasis in this book has been centred around worms found in India, though research pertaining to earthworms around the world at large has also been discussed. Some of the thoughts and ideas expressed in this book may already have been expressed, discussed and published elsewhere by others without acknowledgement here. I sincerely apologise for any such inadvertent use.

I acknowledge with special thanks the assistance rendered by my team (in alphabetical order) – Adil, Anne, Asrar, Aswathy, Chitra, Dhakshi, Geetha, Hamza, Jagan, Josephine, Lalitha, Mohsina, Naveed, Prakasam, Priscila, Radha, Ramesh, Sabitha, Samuel, Sosamma, Sundar, Thangaraj, Yusuf at the *Institute of Research in Soil Biology and Biotechnology*, The New College, Chennai.

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I record my sincere appreciation to my very best 'earthworm' friends – Trevor Pearce, Edward Giordano, Venkatramani, G. and Thiagarajan, G.

I thank my brother Nirmal, M. B. and the entire team at EXNORA International for incorporating vermitech in their agenda of civic programmes and propagating it widely in homes for recycling of domestic garbage at source.

I would also like to place on record my appreciation and thanks to my beloved family – my wife Tasneem and my daughter Azra, her husband, Ashraf and my cute granddaughters, Asma, Hafsa & Husna – for their encouragement and support. I remember at this point, my dear father, mother and brother who are no more.

A special word of thanks to my uncles, Dr Syed Khaleefathullah and Professor Sulaiman Modi who had been my friends, philosophers and guides.

The multitude of people who cannot be mentioned individually, who deserve my gratitude are a host of valuable friends, especially Dawood Sharief, and the farmers who still preserve the knowledge of traditional composting and organic farming.

To Almighty I bow with reverence and gratitude.

SULTAN ISMAIL
July 2023

Contents

I.	Introduction	1
II.	Earthworms: Ecological Types	5
III.	Earthworms: Structure	13
IV.	Earthworms: Life Cycles	22
V.	Earthworms: For Culture	29
VI.	Vermiculture and Vermitech	34
VII.	Experiments from the Field	53
VIII.	Earthworms: Their Applications in Organic Agriculture	68
IX.	Earthworms: End Uses and Potential	76
	Epilogue	81
	Bibliography	82
	Glossary	100

I

Introduction

It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly organised creatures.

– Darwin, C., (1881)

Macroinvertebrates play a definite and prominent role in regulating soil processes but among them termites and earthworms play a vital role in maintaining soil fertility and in bringing about efficient nutrient cycling.

An earthworm is more familiarly known to the student of biology as an organism provided for dissection; to the angler as a bait for fishing; and to the common man as 'yet another creature'. Darwin (1837), though popularly known for his theories on evolution, was one of the pioneers who highlighted the role of earthworms in soil health.

It has been said, 'A gardener is one who has a good sense of humus.' Humus is the product of biological action on organic matter. Earthworms form a major component of the soil system and these seemingly unimportant creatures – true optimists, par excellence have been silently ploughing the land for millions of years and assisting in the recycling of organic nutrients for the efficient growth of plants. Earthworms therefore, represent a key component in the biological strategies of nutrient cycling in soils and the structure of their communities* gives a clear indication of the type of soil system they inhabit (Lavelle, 1988). These little creatures are known to have

originated during the Precambrian era, and reports (Piearce, *et al.*, 1990) have described a fossil of an embryonic earthworm, with part of its cocoon wall intact, found beneath a late Bronze Age midden at Potterne, Wiltshire, UK.

Unfortunately, the advent of chemicals and their large scale application in the name of fertilisers and biocides has drastically changed the structure of soils and has, in most cases, eliminated soil organisms.

Today we realise to our dismay that soils are dying!

The discontinuous distribution of earthworms in certain soils under pasture or cultivation is a result of earthworms exhibiting endemism (Lavelle *et al.*, 1989). Human interference in natural ecosystems through modern practices of agriculture, silviculture and horticulture, involving large scale application of fertilisers and biocides, has been responsible for the destruction of endemic soil fauna.

It must be realised that only soil along with its faunal components constitutes living soil.

Earthworms can be called biological indicators of soil fertility, for soils with earthworms most definitely support healthy populations of bacteria, fungi, actinomycetes, protozoans, insects, spiders, millipedes and a host of other organisms that are essential for sustaining a healthy soil.

Earthworms not only inhabit the soil, but by virtue of their activity, contribute to the physical and chemical alterations in the soil, leading to soil fertility and plant growth. Soils inhabited by earthworms have casts which are, in turn, richly inhabited by microorganisms.

Beddard (1912) described earthworms as 'segmented bristle-bearing worms contributing at large to the biomass of soil invertebrates, particularly in the temperate and the tropical regions of the world.' Their role in the turning over of the soil drew the attention of Aristotle (cf. Shipley, 1970) who called earthworms the 'intestines of the earth.' Darwin (1881) discovered the role of earthworms in the breakdown of dead plant and animal material in soil and forest litter, and in the maintenance of soil structure, aeration and fertility. His findings that earthworms play a beneficial role in soil formation and soil fertility was acknowledged by Hensen (1877), Müller (1884) and Urquhart (1887).

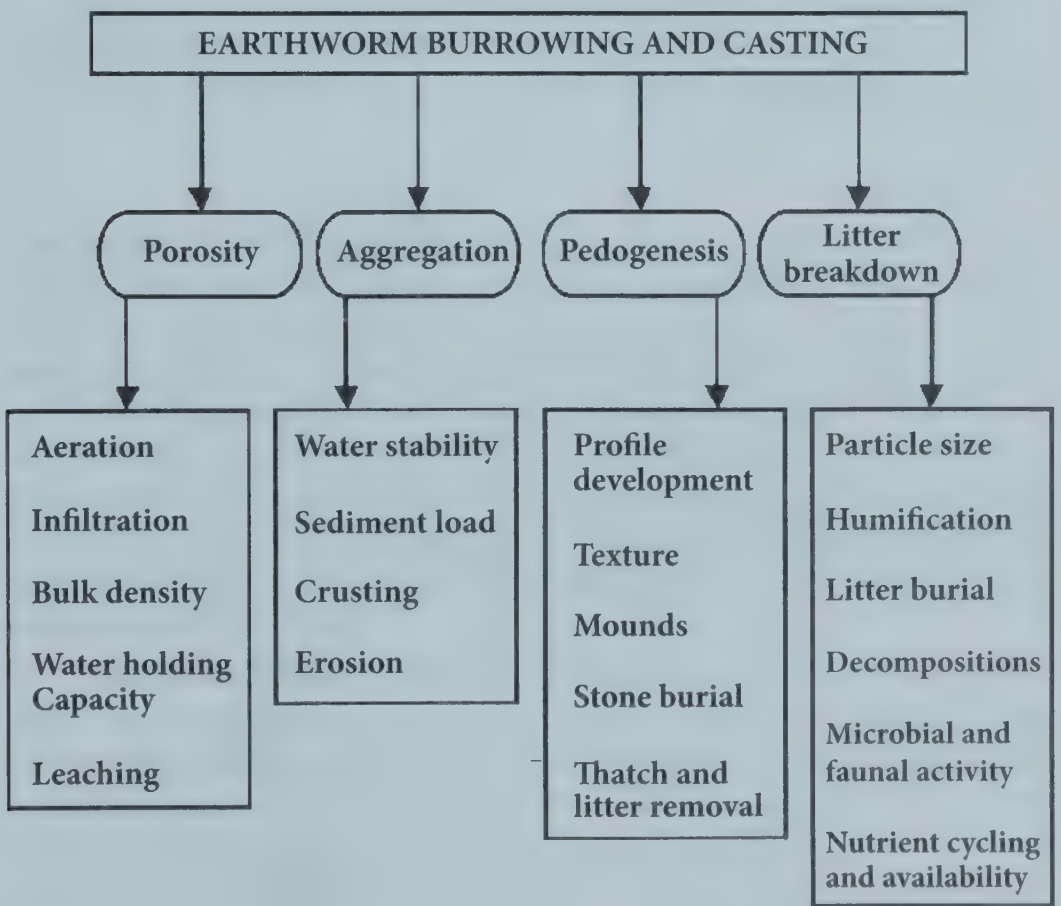
Darwin's conclusions led to an upsurge of interest in earthworms from the late nineteenth century onwards (for example, Vejdovsky, 1884; Beddard, 1895, 1912; Michaelsen, 1900; Stephenson, 1923, 1930; and Bahl, 1950) but, as pointed out earlier by Satchell (1958), the importance of earthworms in agricultural soils is open to question even today more than 160 years after Darwin published his first paper (1837) on the effects of earthworm activity.

The debate goes on... and through the centuries, much before the green revolution, these quiet machines have been carrying out the marvellous function of ploughing the soil and fertilising it. They have helped the angler have his day and have helped people in the remote habitats of China, India and Iran prepare decoctions and potions for some ailment or the other.

As awareness grows about the importance of earthworms to soil fertility and plant growth, every individual – the farmer, the agriculturist, the horticulturist, the gardener, the common man, the housewife and the child who goes to school – must be educated on the valuable contribution that earthworms can and do make to life on earth.

The effects of earthworms in soil

A flow chart on descriptions of earthworm activities in soil and associated properties and processes based on collective observations of several scientists (for e.g. Satchell, 1983; Lee, 1985; Lavelle *et al.*, 1989; Ismail, 1997; Kale, 1998) is provided below:



Through this book you will have the opportunity to know what earthworms are, their creditability, their potential and how they are useful in not only upgrading the lands but also in organic waste recycling.

II

Earthworms: Ecological Types

If we compare, for example, the significance accorded to ornithology and the multitude of birdwatchers studying about one kilogram of birds per hectare, with the extremely limited number of research workers interested in the hundreds of kilograms or tonnes per hectare of earthworms, we must conclude that our knowledge of ecosystems is fundamentally distorted by our aboveground, visual perception of nature and our ignorance of life below ground.

Bouché, M.B., (1985)

Most earthworms are terrestrial organisms which live in the soil. But some species, like *Pontodrilus bermudensis* lead a comfortable life in estuarine waters. Though taxonomic classification is desirable to identify a given species of earthworm, a classification based on ecological strategies is more suitable for harnessing earthworms for the benefit of mankind. Even such classifications may prove unsuitable, as, particularly in tropical climates, these worms may be found under moist, rotting logs, at the bases of paddy plants, on damp roofs, terraces and trees, and even beneath the traditional domestic grinding stone as sufficient organic matter gets deposited in such areas due to constant use.

Taxonomically, five large families of earthworms have been listed worldwide – the Moniligastridae, Megascolecidae, Eudrilidae, Glossoscolecidae and Lumbricidae (Jamieson, 1971). Julka (1988) has described the Indian Oligochaeta in the *Fauna of India*. Taxonomic studies of Indian earthworms were, to a large extent, dominated by Dr G. E. Gates, the doyen of modern earthworm taxonomy. During the last decade and half however, much taxonomic work on Indian earthworms has been carried out by Julka (1975, 1976, 1977, 1978, 1979, 1981 and 1983 *et seq*); Jamieson (1977) and Easton (1982).

Trophic classification of earthworms

Earthworms are generally classified as saprophages*, but based on their feeding habits they are classified into detritivores and geophages (Lee, 1985).

Detritivores feed at or near the soil surface. They feed mainly on plant litter or dead roots and other plant debris in the organic matter-rich surface soil horizon or on mammalian dung. These worms are called humus formers and comprise the epigeic and anecic forms. *Perionyx excavatus* (Plate 1), *Eisenia fetida, Eudrilus eugeniae, Lampito mauritii* (Plate 2), *Polypheretima elongata, Octochaetona serrata* (Plate 4) and *Octochaetona surensis* are a few examples of detritivorous earthworms.

Geophagous worms, feeding beneath the surface ingest large quantities of organically rich soil. These are generally called humus feeders and comprise the endogeic earthworms. *Octochaetona thurstoni* (Plate 3) and *Metaphire posthuma* are two common examples.

Bouché (1977) classified earthworms into epigeics, anecics and endogeics (fig. 1) laying stress on ecological strategies.

Epigeics are surface dwellers serving as efficient agents of comminution and fragmentation of leaf litter. They are phytophagous*. They generally have no effect on the soil structure as they cannot dig into the soil.

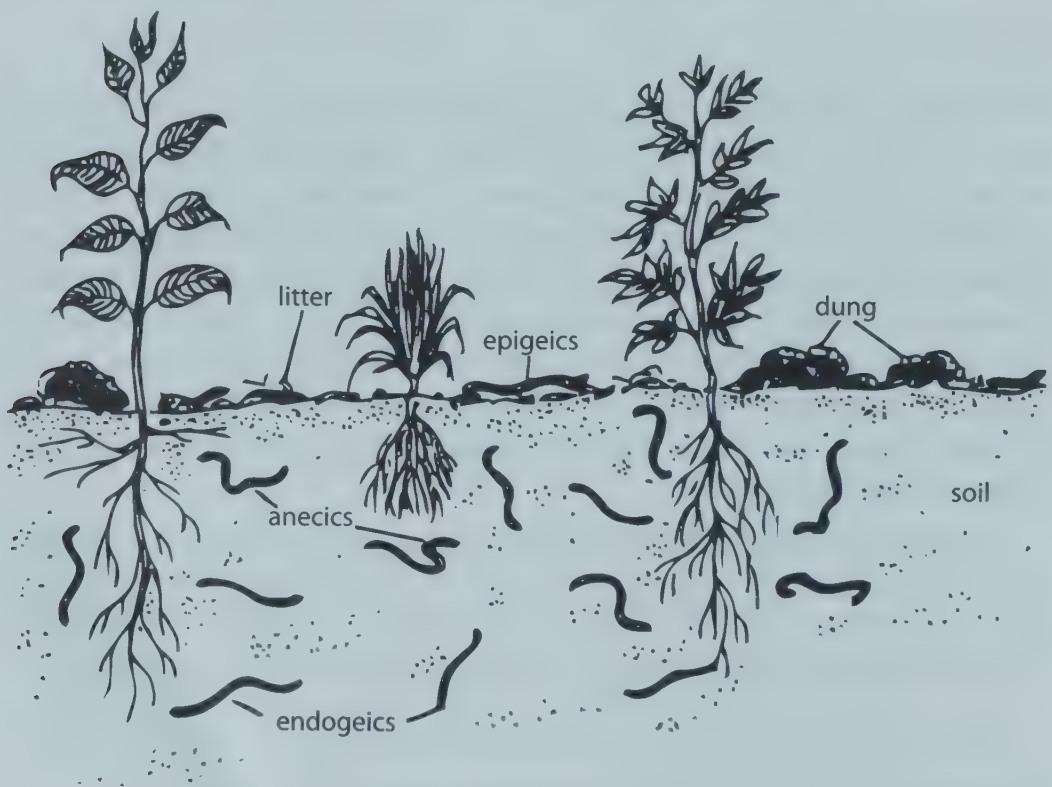


Fig 1: Earthworm classification based on ecological strategies

Anecics feed on the leaf litter mixed with the soil of the upper layers and are said to be geophytophagous*. They may also produce surface casts generally depending on the bulk density of the soil.

Endogeic earthworms are geophagous. They live within the soil deriving nutrition from the organically rich soil they ingest.

The contrasting behaviour, morphology and physiology of soil-dwelling, non-pigmented forms and surface-living red-pigmented forms, represent evolutionary poles arising from r and K selection with subsidiary adaptive radiation (Satchell, 1980).

Drilosphere

The drilosphere comprises earthworms and the entire volume of soil and litter that they influence through their activities, in mutualistic association with free soil microorganisms and, possibly, a few obligate, symbiotic protozoa or bacteria (Rouelle *et al.*, 1985; Lavelle and Martin 1992). Anecic and endogeic earthworms associate with the free-living soil bacteria to constitute the drilosphere (fig. 2). It has been established that soil ingested by earthworms and the intestinal mucus together stimulate microbial activity. An organised creation of structures and burrows, predominantly the vertical burrows made by the anecic earthworms and the horizontal burrows by the endogeic

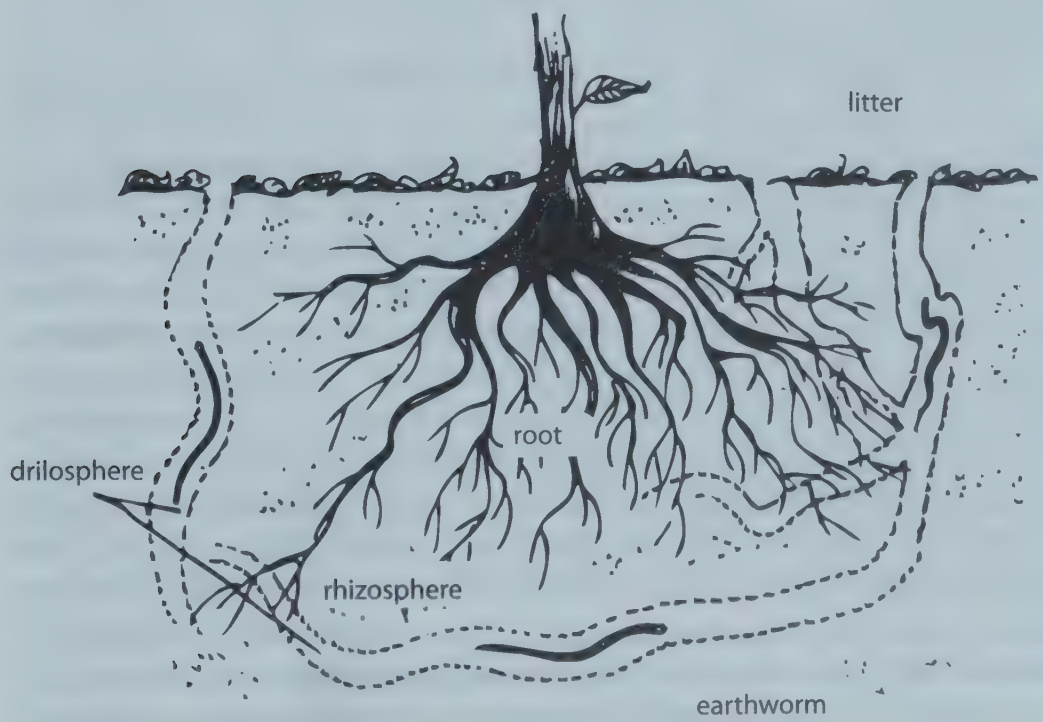


Fig 2 : Drilosphere

worms, modify the accumulation and circulation of water and gases in soils, which further influence the decomposition of soil organic matter (Tisdall and Oades, 1982).

Physical effects of earthworms on soils

Anecic earthworms which are predominantly responsible for making vertical burrows, cast liberally on the soil surface especially in compact soils (Habibullah and Ismail, 1985; Krishnamoorthy, 1989), while endogeic earthworms, which generally make horizontal burrows, preferably deposit their casts within the burrows. It is interesting to note that surface casts play a significant role in soil profile development while the casts deposited beneath the soil surface contribute to pedogenesis*. Earthworms are known to be responsible for soil comminution (Evans, 1948; Teotia *et al.*, 1950; Shrikande and Pathak, 1951; Joshi and Kelkar, 1952). It is however unlikely that physical comminution of this kind will have much significance considering the comparatively short time spent by the soil in the gizzards of earthworms (Lee, 1985). Earthworm casts develop as soil aggregates (casts getting stabilised after they are excreted) by forms of gums that result from microbial digestion of their organic components (Waksman and Martin, 1939) or by the binding effect of fungal hyphae (Parle, 1963b). The quantity of surface casts produced by earthworms in a variety of environments ranges from 0.25 kg m^{-2} in Australian pastures (Barley, 1959) to 25.75 kg m^{-2} in German pastures (Graff, 1971).

Earthworms, to a large extent, alter soil porosity and it has been reported by Wollny (1890) that soils with earthworms show an increase in soil-air volume from eight per cent to 30 per cent. These characteristics relate earthworms to water infiltration and the water holding capacity of soils. Stockdill's (1966) data relates available moisture in soils (0–30 cm) under pasture plots with and without lumbricid earthworms in New Zealand. Several experiments have been designed to study the effect of earthworms on the physical properties of soils especially in relation to water movement. Though there are many disadvantages in experimental setups related to such experiments they are most useful and necessary to identify functionally important morphological variables (Diestel, 1992). Besides anecic species like *Lumbricus terrestris* (Joschko *et al.*, 1989), endogeic species like *Apporrectoidea caliginosa* and *Apporrectoidea rosea* (Joschko *et al.*, 1992) also construct highly effective water conducting channels when the soil is saturated or when the soil is flooded with water. The physical properties of soils also control the biological activities of soils. Factors like water, gas and heat transfers are regulated by the topology of the porosity system (Kretzschmar and Monestiez, 1992).

Trampling affects the physical and chemical properties of soils (Briggs, 1978) and the nature and abundance of vegetation and fauna which in turn may lead to the depletion in earthworm numbers and biomass (Chappell *et al.*, 1971; Aritajat *et al.*, 1977; Briggs, 1978; Piearce, 1984; Piearce *et al.*, 1995). Though surface species are largely affected by trampling, the deep burrowing species like *Apporrectoidea longa* are particularly resistant to this.

The hope of maintaining local varieties of anecic earthworms in difficult environments has been realised through *L. mauritii*. This species can not only be maintained easily but also can be bred and cultured in sands and sandy soils amended with commonly available local inputs. Such cultures do not only serve as *in situ* soil conditioners but also gradually support plant growth (Anne Grace and Ismail, 1994).

Chemical effects of earthworms on soils

Earthworms affect the chemical composition of soils and are also responsible for the distribution of plant nutrients and their transport because they consume large quantities of surface litter and organic material. Earthworms process the transport of organic material to the subsurface layers of the soil and during this process much matter is ingested, macerated and excreted. Earthworms also contribute several nutrients in the form of nitrogenous wastes. Ammonia, which forms a large proportion of the nitrogenous matter excreted by earthworms (Cohen and Lewis, 1949) may cause a temporary rise in the soil pH. Earthworms, however, are more sensitive to the components which are required to make a particular pH than to the pH as such (Magdoom and Ismail, 1986).

Several researchers have compared vermicasts with the surrounding soils and their results, since Dussérre (1902), have invariably shown that casts have a higher base-exchange capacity and are generally richer in total organic matter, total exchangeable bases, phosphorus, exchangeable potassium and manganese and total exchangeable calcium. Earthworms however, seem to favour nitrification (Keller, 1893; Puh, 1941), since they increase bacterial population (Parle, 1963 a, b) and soil aeration (Heymons, 1923; Anstett, 1951). Though *Azotobacter** may decrease during its passage through the earthworm gut (Ruschmann, 1953, 1954), it may considerably increase outside the gut in vermicasts (Stöckli, 1928). As the protein content of earthworm tissue is high (Alawdeen and Ismail, 1986), on decomposition it also yields nitrate nitrogen (Russell, 1910).

Earthworms do not ingest all the plant litter, dung and other organic material that they remove from the soil surface and, in fact, of the amount that is ingested, very little is digested (Lee, 1985). The ingested organic material is

macerated, mixed with ingested inorganic soil material, passed through the gut and excreted as casts, with most of it very little changed chemically, but finely ground physically. This, in fact, enhances surface area and therefore promotes microbial activity. The most important effect of earthworms may be the stimulation of microbial activity that occurs in casts (Nowak, 1975) which enhances the transformation of soluble nitrogen into microbial protein, preventing their loss by leaching to the lower horizons of the soil. Forty per cent of the total aerobic nitrogen fixers, 13 per cent of the anaerobic nitrogen fixers and 16 per cent of the denitrifiers are present in the drilosphere with the maximum population being within 20–40 cm of the soil (Bhatnagar, 1975). The C : N ratios of casts are, however, a little higher than that of the surrounding soil (Graff, 1971; Lavelle, 1978) with the quantity of carbon and nitrogen excreted in the casts being sometimes very large (Syers *et al.*, 1979).

Lee (1983) summarised the influence of earthworms on soil nitrogen and nitrogen cycling. According to him, nitrogenous products of earthworm metabolism are returned to the soil through casts, urine, mucoproteins and dead tissues of earthworms. The nitrogen input in the soil from dead earthworm tissues alone may be equivalent to 67 g m^{-2} yr^{-1} (Satchell, 1963); and that from excretion of urine and secretion of mucus to 10 g m^{-2} yr^{-1} (Needham, 1957). Other sources of nitrogen for soils include decaying roots, excreta from invertebrate and vertebrate fauna, dead plant and animal material and nitrogen fixation by microbes. It is likely, according to Scheu (1994), that there is an earthworm mobilisable nitrogen pool in the soil which is linked to earthworm mobilisable carbon resources and that physically protected nitrogen and carbon contribute substantially to the earthworm mobilisable nitrogen and carbon pool.

Biological effects of earthworms on the soil

Earthworms may affect soil micro-floral and faunal populations either directly or indirectly by three main mechanisms:

1. Comminution, burrowing and casting

Comminution increases surface area for decomposition by microflora, effecting nutrient availability and preconditioning status of food for further use by other organisms (Martin and Marnissen, 1993). Burrows with abundant oxygen and organic matter, and casts with high assimilable carbon content, favourable water regime and higher concentrations of many nutrients (Lee, 1985) provide excellent conditions for micro-floral and faunal proliferation.

2. Selective grazing

Selective grazing may reduce the number of some organisms, and increase others that could be beneficial (Lussenhop, 1992).

3. Dispersal

Earthworms may disperse microorganisms either on their body surface or after surviving passage through the gut. Epigeics and anecics are more important in dispersal of surface-dwelling organisms and endogeics for sub-surface dispersal.

Mutualistic digestion

Earthworms, though, consume some bacteria, which leads to their decrease in numbers; the total microbial activity (as measured by O_2 consumption) is generally enhanced in their guts (2–12 times higher), compared to undigested soil and casts. The gut region provides the optimum incubation temperature, near neutral pH and abundant soluble organic carbon (mucus secreted by the earthworm and intimately mixed with litter, organic matter, and high water content) creates ideal conditions for high bacterial activity, reducing the oxygen content of the gut.

The result is a mutualistic digestion system where the ingested bacterial activity is stimulated by mucus secretion of the earthworm, which in turn increases the digestion of the recalcitrant substances ingested by the earthworms, realising the metabolites in the hind gut that are absorbed by them (Barois and Lavelle, 1986).

Synergistic role of the earthworm and microbes in improving soil fertility.

The mutualistic digestion-system between the earthworms and the microorganisms leads to the release of nutrients tied up in the organic matter and the biomass that increases the activity of the fungi, bacteria, algae, protozoa, and bacteriophagic nematodes in the soil. This increases the enzymatic activities of the soil and nutrient mineralization. Production of metabolites such as plant growth regulators by the microorganisms also accelerates plant yield.

The burrowing and casting activity of the earthworms in soil increases the dispersal of beneficial microorganisms such as VAM, *Frankia*, and *Rhizobia* that colonise the root and help in plant root growth. The dispersal of bio-control agents such as fungi, bacteria, and beneficial nematodes also reduces insect pests and plant diseases.

The effect of absence of earthworms in soils

A number of non-renewable products go into the making of chemical fertilisers and biocides which have been pumped into the soil and through the soil into plants and the subsequent food chains. These might have had some immediate rewards in agriculture but in the long run they have been largely responsible for soil degradation eventually leading to lifeless soil. The saying, 'We have not inherited the earth from our ancestors, but have borrowed it from our children' would remain a mockery if we do not do something about saving 'dying' soils. Soil is said to have 'life' only when it is holistically looked upon along with its inhabitants in the form of flora and fauna.

The initial greed for a very high NPP (Net Primary Production), followed by the lavish desire to harness very high NCP (Net Community Production) has led to the massive application of chemicals to soils in the form of fertilisers to achieve the former and biocides to achieve the latter.

'Insecticides breed resistance. To win the war on bugs, people must learn when not to spray' (Ffrench–Constant, 1995). However, the question is, who learns when not to spray? An average farmer in India, either marginal or working as labourer in larger farms, sprays insecticides without even wearing self-protection gear. These sprays whether foliar or basal, gradually have a detrimental effect on non-target species, ranging from microbes to human beings. They also cause the destruction of super predators and beneficial organisms like spiders, wasps and other parasitoids which check insect parasites.

The concept of soil fertility is relatively new, propagated with the advent of the green revolution. The traditional concept has, however, been soil health, which accounts for the physical, chemical and biological components of the soil. In this context, our observations indicate the earthworm as the *pulse* of soil health. A healthy pulse indicates a healthy soil.

III

Earthworms: Structure

As the classroom type of the Annelida, 'the earthworm' is familiar to every student of biology. Dissection manuals package its anatomical features, and numerous texts admirably relate earthworm form and function. Beyond these frontiers, students and teachers alike are met by a bewildering mass of publications ranging in content from the military value of earthworms as survival food, to the species stored by moles. The volume of this literature is quite exceptional for an invertebrate group which is important neither as pest nor food. It stems from the inherent zoological interest of the earthworm as a terrestrial form retaining many of the characteristics of its aquatic ancestors; from its convenience as an experimental animal for behaviourists and physiologists; and from its effects on soil fertility.

SATCHELL, J.E., (1972)

External features

Shape and size

Earthworms are long and cylindrical (fig. 3). There is very little variation in the shape among the different species of earthworms and the morphological differences, if any, are greatly limited to the length of the worms, the number of segments, the position of the clitellum and external apertures which are

Fig. 3: External features of the earthworm

present both as dorsal pores and the ventral openings of the reproductive system. Deep burrowing species have more elongated bodies than surface dwellers do, and adult worms have more elongated bodies than juveniles. Moreover, the long bodied species tend to have more segments than the short-bodied ones (Piearce, 1983). *L. mauritii* is 80–210 mm in length with a diameter of 3.5–5 mm; *M. posthuma is* 115–130 mm in length with a diameter of 5 mm, while *P. excavatus is* 23–120 mm in length with a diameter of 2–5 mm.

Segments

The body of the worm is encircled by a large number of grooves which divide it into a number of compartments called segments. This segmentation is characteristic of the Phylum Annelida (Latin: *annulus*: ring) to which the earthworm belongs. The segments vary not only in number in the different species but also in their width within their species, with the anterior segments generally being wider. The number of segments vary from 80 to 100 or more. In *L. mauritii* there are about 165 to 190 segments, while M. *posthuma* has 140 segments and P. *excavatus* about 165 segments. The last segment is called the anal segment and it has a perforation for the anus at the hind end.

The first segment of the earthworm into which the mouth opens is the peristomium. On the dorsal surface of the peristomium is a lobe-like structure called the prostomium which overhangs the mouth. This association of the prostomium with the peristomium varies in different species of earthworms and also serves as a taxonomic tool. Significantly, the type of prostomium varies with the trophic character of the earthworm species. The way in which the prostomium is connected to the peristomium is said to be zygolobous, prolobous, epilobous, or tanylobous (fig. 4). The prostomium in *L. mauritii* is prolobous or half epilobous, in *M. posthuma* tanylobous and in *P. excavatus* it is epilobous.

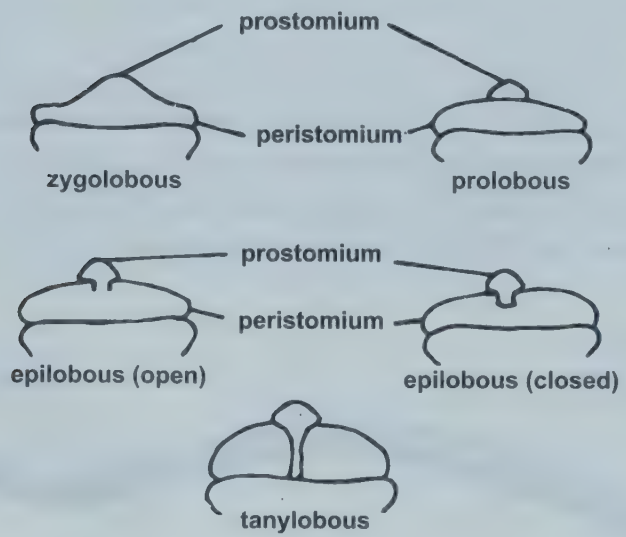


Fig 4 : Various forms of prostomium

Clitellum

In mature worms a few segments in the anterior region of the worm may be found to be swollen with a glandular thickening of the skin. This region is called the clitellum. The segments are not clear in this region and they generally do not have body setae. The number of segments forming the clitellum vary in the different species of earthworms. In *L. mauritii* segments 14 to 17 (total = 4) form the ringshaped clitellum, in *P. excavatus* it is formed by segments 13 to 17 (total = 5) and in *M. posthuma* it is formed by segments 14 to 16 (total = 3). In lumbricids the clitellum is generally found at the farther segments.

Colour

The colour of earthworms generally ranges from a brownish-black tinge to purple with some exceptions. Generally, the dorsal side of the worm is darker while the ventral side is paler. *L. mauritii* is light brown in colour, with a purplish tinge at the anterior end, while *M. posthuma* has a rich brown colour. *P. excavatus* is a deep purple to reddish brown colour dorsally and is pale brown ventrally.

Setae

The body of the earthworm is characterised by the presence of setae called the body setae. In each segment, after the first, these tiny bristles formed of chitin are found buried in small pits in the skin, called the setal or setigerous sacs. Each seta is usually 'S' shaped with a swollen middle part. The setae fall out and are replaced several times during the lifetime of the worm. Setae help the worm in locomotion by getting a firm grip of the substratum. They are operated by special muscles. The number of setae present in each segment of the earthworm may vary in different groups (fig. 5). The lumbricids and certain megascolecids are characterised by eight setae per segment of the body. This arrangement is called the lumbricine arrangement. Many species of megascolecids are characterised by the perichaetine arrangement of setae, as they have more than eight setae per segment. The arrangement of setae on the segments and the intersetal distances also serve as taxonomic characters for each species. In *L. mauritii* and *M. posthuma* the setae are arranged all around the body except mid ventrally. In *P. excavatus* the setae are more in number ventrally than dorsally. This is an ecological adaptation as *P. excavatus* is an epigeic worm and requires setae mainly on the ventral side for surface movement.

Modified setae may also be found in other parts of the body. These perform specialised functions, especially during reproduction. The setae

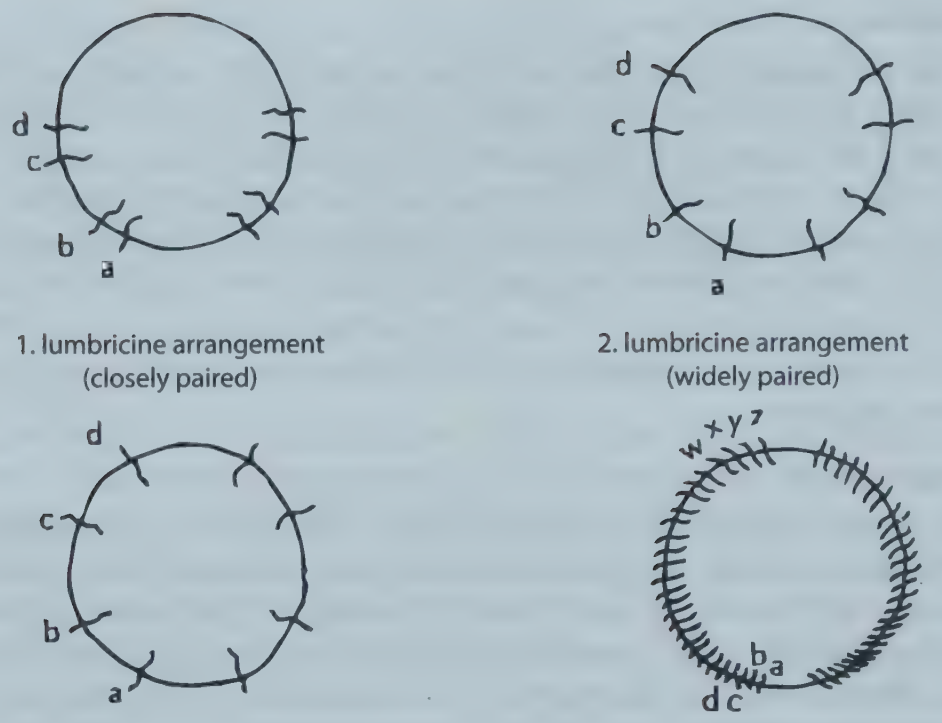


Fig 5: Arrangement of setae

connected with reproduction, generally called the genital setae, may again be distinguished into copulatory setae when they are associated with the spermathecal openings and penial setae when they are associated with the openings of the male pores. At higher magnifications, the setal structures reveal many astonishing modifications giving an insight into their functional anatomy (Ismail, 1982, 1985).

External apertures

Besides the apertures for the mouth and the anus the earthworm has the following external apertures (fig. 6):

- dorsal pores,
- spermathecal openings,
- openings of oviducts or female pores,
- openings of spermiducts or male pores,
- nephridiopores.

Body wall

The body wall is thin and consists of the following layers arranged sequentially from the outside:

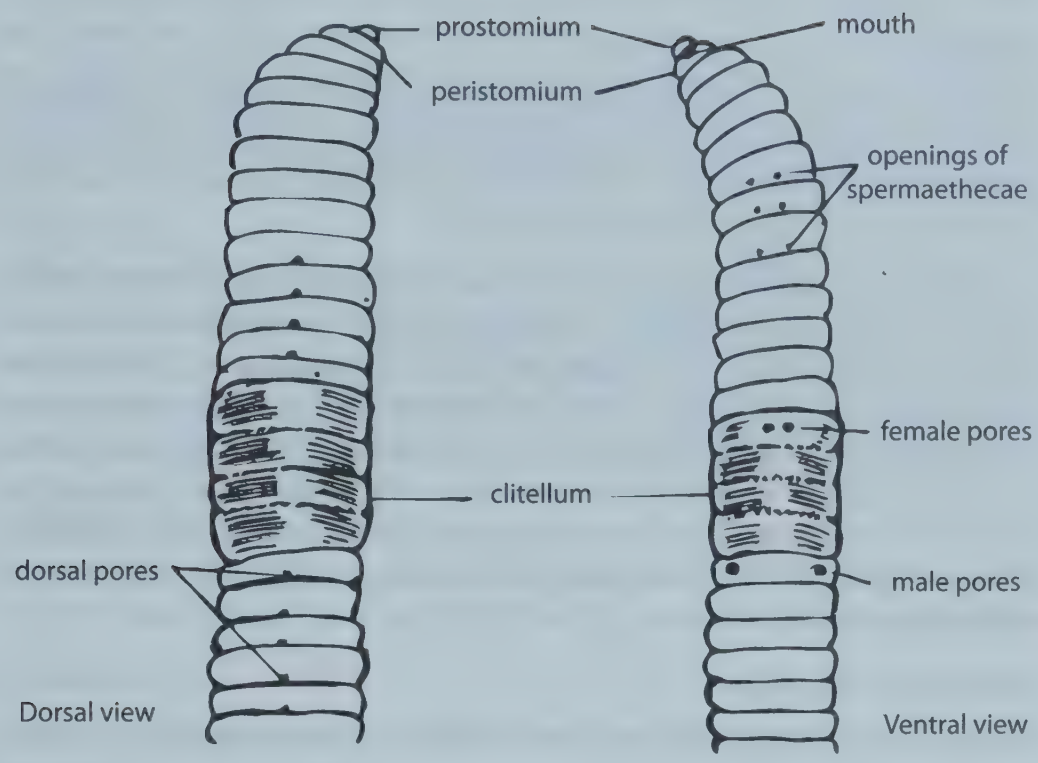


Fig 6: External apertures with ref to L. mauritii

a) a thin, transparent cuticle,

b) the epidermis made up of cells, many of which secrete mucus to keep the skin moist. The epidermis consists of pits in which the setae are embedded,

c) the dermis, made up of a thin layer of connective tissue,

d) a layer of circular muscles,

e) a layer of longitudinal muscles, and

f) the coelomic epithelium.

Locomotion

Locomotion is effected by the contraction and relaxation of the muscular body wall, aided by the turgescence of the coelomic fluid which has been called the hydraulic skeleton. As the earthworm moves, the circular muscles contract first making the body thinner and longer. This is followed by the contraction of the longitudinal muscles which brings about the shortening of the body. With the front portion of the body fixed by the points of support, the hind part is drawn up. The body setae enable the worm to get a firm grip on the ground during movement.

Internal features

Body cavity

The body cavity is a coelom (hollow) lined with the coelomic epithelium which forms the visceral layer around the alimentary canal and the parietal layer lining the body wall. The body cavity communicates with the exterior by the reproductive and excretory apertures.

The coelom contains the coelomic fluid in which the coelomocytes, that is, the mucocytes, vacuolocytes, small granulocytes, large granulocytes and lymphoidocytes (Kale and Krishnamoorthy, 1979) are present. The coelomocytes are known to play a major role in regeneration, immunity and wound healing (Kindred, 1929; Chapron, 1932; Liebmann, 1942, 1947; Burke, 1974; Fischer, 1977). The coelomic fluid exudes on the body surface through the dorsal pores and keeps the skin moist, a condition necessary for respiration of the earthworm. The fluid also helps to kill bacteria and other parasites which may attack the worm.

Feeding and digestion

The mouth leads into the buccal cavity which is followed by a thick-walled, muscular pharynx. The pharynx leads into the esophagus which leads into a thick-walled gizzard. The gizzard is followed by the intestine which is narrow and straight for the first few segments (around 14 segments) after which it is wide and sacculated up to the anal segment where it opens to the outside through the anus.

The intestine has secretory cells and its dorsal wall has a fold which projects into the lumen throughout its length. This fold, called the typhlosole, consists of a lining of the intestine, enclosing the blood vessels. The typhlosole increases the absorptive surface of the alimentary canal.

Anecic earthworms in general, and endogeic earthworms in particular, swallow large quantities of soil and utilise the decaying animal and vegetable matter contained in it. While the worm is feeding, the buccal chamber is everted and the food is drawn into the mouth by the sucking action of the muscular pharynx. Decaying vegetation is dragged into the burrows of anecic earthworms and is eaten after being moistened with the juice secreted by the glands in the pharynx. The gizzard serves to break the food into fine particles which is then sent into the intestine where digestive juices act on the particles to digest proteins, fats and carbohydrates. Undigested food and soil are egested through the anus as castings (vermicastings).

Circulation

The blood consists of colourless corpuscles suspended in plasma. The haematocytes which are generally present in the earthworms include the trephocytes, granulocytes, vacuolocytes, large vacuolated cells and lymphoidocytes (Kale and Krishnamoorthy, 1979). The red colour of the blood is due to the presence of hemoglobin which is dissolved in the plasma.

Respiration

There are no special organs of respiration. Respiration takes place through the body wall. The outer surface of the skin is richly supplied with blood capillaries which aid in the diffusion of gases. Oxygen diffuses through the skin into the blood while carbon dioxide from the blood diffuses out. The skin is kept moist by mucous and coelomic fluid, and this facilitates exchange of gases.

Excretion

Excretion is effected by nephridia. The arrangement of nephridia varies in different groups of earthworms. The following types of nephridia may be seen:

Meganephridia

These nephridia are otherwise known as enteronephric nephridia as they are connected to the intestine.

Micronephridia (integumental nephridia)

These consists of a large number of minute, finger-shaped tufts of tubes. These have no internal openings and are called exonephric or integumental nephridia.

Pharyngeal or tufted nephridia

They are made up of paired tufts of coiled nephridial tubules on each side of the esophagus and gizzard. Their ducts run in separate bundles and open into the esophagus as in *L. mauritii* or into the pharynx and buccal cavity as in *M. posthuma.*

Reproduction

Earthworms are hermaphrodites, that is, both male and female reproductive organs are present in a single worm.

Copulation

Though earthworms are hermaphrodites, self-fertilisation does not generally occur. During copulation two worms adhere to each other by their ventral surfaces with their head ends pointing in opposite directions. The

spermatozoa from the male openings of one worm are then transferred to the spermathecae of the other worm.

As the time for laying eggs approaches, the clitellum forms a viscid, girdle-like structure which hardens into a tough capsule (cocoon) encircling the body of the worm. At the time of egg laying, the girdle is pushed forward by the wriggling movements of the body of the worm. The girdle slips off the anterior end of the worm and its two ends are closed forming a capsule containing the sperms and ova. The capsule has a nutritive, albuminous fluid secreted by the glands of the clitellum. Fertilisation takes place in the egg case or cocoon which is deposited in a moist place.

Cocoon

Cocoons are small, spherical and translucent structures. The size of a cocoon varies according to the species (Plate 5). The cocoons of the epigeic species have terminal strands which probably help the cocoon adhere to litter till they hatch. Though many eggs are contained in each cocoon only a few develop into young worms and when they are ready, they crawl out of the cocoon. The colour of the cocoon changes gradually as it develops from the freshly laid stage to the time of hatching as seen in *L. mauritii* (Plate 6).

Regeneration

Earthworms have the power to regenerate segments which are lost. Regeneration takes place at the posterior end more easily than it does at the anterior end. If a worm is cut into two, the anterior half will regenerate a tail, but the posterior half usually cannot form the head part. If the animal is cut lengthwise, it dies as regeneration does not take place in this case.

Bioluminescence*

A few species of earthworms are known to exhibit bioluminescence. Bioluminescence among earthworms has been reported in *Octochaetus multiporus* (Johnson *et al.*, 1966), *Eisenia* and *Diplocardia* (Cormier, 1969), *Microscolex heteroptera* (Dyne, 1979), *Spenceriella cormieri*, *S. curtisi*, *S. minor*, *S. noctiluca*, *Fletcherodrilus unicus*, *F. fasciatus*, *Pontodrilus bermudensis*, *Diplocardia longa* (Jamieson and Wampler, 1979, 1980) and in *L. mauritii* (Ismail and Kaleemurrahman, 1981; Ismail and Santhanam, 1984, Ismail *et al.*, 1985). Bioluminescence occurs due to the presence of luciferin and luciferase locked in chloragogen cells which burst open when they are secreted through the dorsal pores on the body surface. The emission levels of *L. mauritii* range from 4.41×10^{13} photons to 8.90×10^{14} photons with an average light output of 3.29×10^{14} photons (Ismail, 1983).

Many researchers have been puzzled by the occurrence of bioluminescence in earthworms and it has been proposed that this mechanism is probably associated with defense against nocturnal predators, or for the social function of attracting members of the same species or perhaps for enhancing sexual attraction (Jamieson and Wampler, 1979; Ismail, 1983).

Bioenergetics

The bioenergetics of earthworms have been worked out to estimate the role of earthworms in energy transfer mechanisms (Senapati and Dash, 1983). Earthworms can process about 10–25 per cent of the net annual energy input into the system (Lakhani and Satchell, 1970) which indicates their place of importance in the decomposer sub-system.

IV

Earthworms: Life Cycles

Earthworms, though in appearance a small and despicable link in the chain of Nature, yet, if lost, would make a lamentable chasm ... worms seem to be the great promoters of vegetation, which would proceed but lamely without them.

Gilbert White (1770)

Life cycle studies

Most studies related to the life cycle patterns of earthworm species are carried out in experimental chambers restricted to laboratory conditions, and based on field observations.

The importance of the earthworm species being generally chosen for life cycle studies is based on its tremendous application potential in vermiculture*. Whether the earthworm species chosen for study are epigeic or anecic or endogeic, the very nature of their differential food trophism has allowed exploitation of their potential.

Soil conditions for the experiment are prepared on the basis of the food preferences and behavioural patterns of the earthworm species, that is, it depends on whether the species is, migratory, horizontal or vertical, and the depth of the soil where these earthworms dwell. Epigeics are surface dwelling or litter dwelling so a minimal amount of soil or no soil may be required. For anecic earthworms, soil upto a depth of 25–90 cm is required while for endogeic earthworms the soil depth required could be similar to that maintained for anecics but with a larger soil volume and organic content.

Life cycle patterns

L. mauritii sheds its cocoons in the upper 20 cm of the soil. These cocoons have an incubation period of about 18 days after which they hatch to release juveniles (Plate 7). These juveniles, grow into the next stage of their life cycle called the non-clitellate stage. At the end of this growth phase, the worms develop a clitellum and are called clitellates.

This growth stage is followed by the reproductive stage when the worms copulate. About ten days after copulation, the worms begin shedding their cocoons in the soil and thus the cycle is completed.

Similar stages are seen in the life cycle of *P. excavatus*. These worms shed cocoons on the litter surface, but incidences have also been recorded of cocoons being laid in the top few centimetres of the soil. A mature worm of this species produces its cocoons either by regular mating or by self-fertilisation (?) or parthenogenesis*. For a cocoon to hatch, grow and in turn produce a cocoon it takes about 60 days in *L. mauritii* and 54 days in *P. excavatus*.

Life cycle – *Lampito mauritii*

Cocoons

Cocoons of *L. mauritii*, at an average, are 6 mm in length and 8 mm across the widest part (Plate 8). Each cocoon is more or less oval in shape and tapers

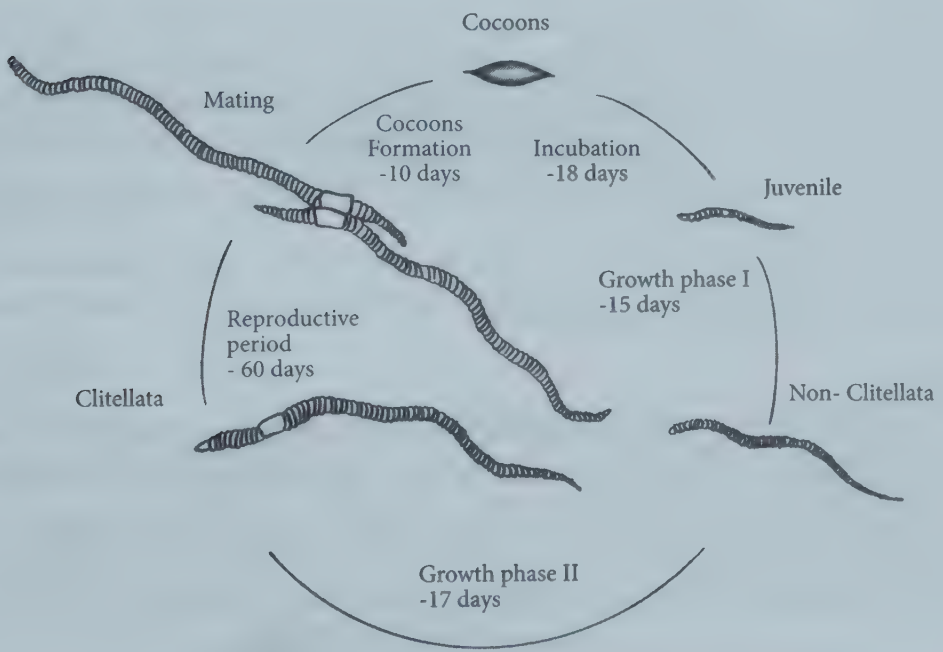


Fig. 7 Life Cycle of Lampito Mauritii

at the ends. When the cocoon is shed, it is a translucent white, with a slightly greenish tinge at the ends. This greenish colour gradually spreads over the entire cocoon changing finally to dark reddish brown before hatching. Though only one juvenile is generally released from each cocoon of *L. mauritii* a maximum of three juveniles have been noticed, but this is rare. The weight of the cocoon is normally between 5 mg and 20 mg, which increases with each stage of incubation.

Though the number of fertilised ova in each cocoon range from one to twenty for lumbricid worms (Stephenson, 1930), often only one or two survive and hatch (Edwards and Lofty, 1972).

Juveniles

On hatching the worms measure 0.8–1.5 mm. in length and weigh about 7 mg. They are a light brownish-red in colour. The length of a juvenile gradually increases to 4 cm and the weight increases to about 150 mg.

Non-clitellates

Juveniles of *L. mauritii* longer than 4 cm which are yet to develop a clitellum are called nonclitellates. The weight of these nonclitellates may range from 150 mg to 450 mg. The non-clitellate stage is an active period in the life cycle of the worm.

Clitellates

Clitellates of *L. mauritii* may grow to 20–25 cm in length. At the time of relaxed locomotion a mature worm may be 25 ± 1.00 cm in length and about 3.50 ± 0.20 g in weight. The younger worms are usually light brown in colour and as they get older the colour changes to dark brown because of an increase in the pigmentation of their epithelial cells. A healthy *L. mauritii* can live for about a year after it is hatched.

Life cycle — *Perionyx excavatus*

Cocoons

The cocoons of *P. excavatus* range between 3 and 5 mm in length and about 6 mm in diameter. The ends of the cocoon taper into tuft-like projections which enable them to adhere to the litter (Plate 8) in their surroundings. These cocoons weigh between 5 and 10 mg. They are translucent white in colour at first and change to light green, pale brown and dark brown before hatching. Usually two to three juveniles hatch out from each cocoon.

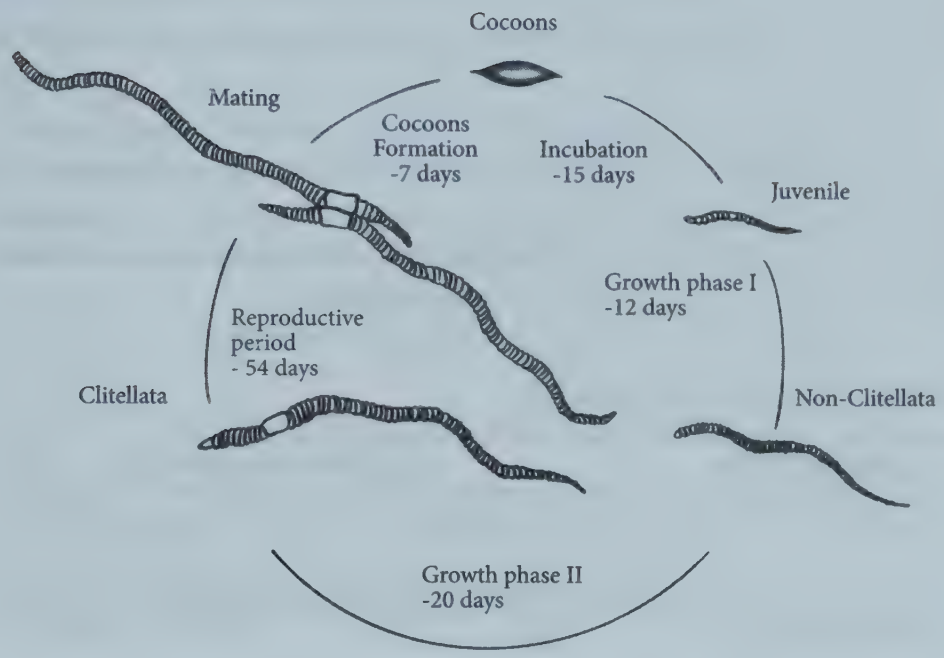


Fig. 8 Life Cycle of Perionyx excavatus

Juveniles

On hatching, the young ones range from 3 mm to 4 mm in length and weigh around 5 mg. They are usually dark pink in colour.

Nonclitellates

Worms longer than 4 cm which are yet to develop a clitellum are called nonclitellates. Their weight may range between 10 and 100 mg.

Clitellates

The clitellates are longer than 6 cm and may, at times, exceed 15 cm in length. These are purple in colour and a few segments at the clitellar region turn very pale in colour during the clitellum formation. As the worms get older their colour deepens to a dark bluish-purple. The clitellum is clearly visible when the worm is ready for copulation and after a few hours of copulation. The life span of *P. excavatus* is around 300 days.

Doubling time

Doubling time (Dt) is the time taken by a given earthworm population to double its number or biomass within a specific area and condition (Odum,1971).

The mean doubling time, with reference to density and biomass, of *L. mauritii* in different organic inputs is 38.05 and 33.77 days respectively (Table 1). Doubling time varies with food intake and based on its food intake the doubling time ranges from 26.96 days to 42.26 days in terms of density and from 29.74 days to 39.38 days in terms of biomass.

Table 1: Doubling time in days

AMENDMENTS	EARTHWORM SPECIES			
	L. mauritii		*P. excavatus*	
	for density	for biomass	for density	for biomass
hay+cowdung	40.06	34.65	20.95	16.64
biogas slurry only	42.26	35.00	9.36	11.68
leaf litter+biogas slurry	36.28	30.53	8.78	11.55
sawdust+biogas slurry	26.96	39.38	9.28	23.24
bagasse+biogas slurry	40.77	33.32	11.26	19.70
kitchen waste+biogas slurry	42.00	29.74	10.71	14.06

In the case of *P. excavatus*, the mean doubling time with reference to density and biomass with different food inputs is 11.72 and 16.14 days, respectively. A wide range of variation in doubling time is recorded from 8.78 days to 20.95 days for density and 11.55 days to 23.24 days for biomass. It is clearly understood today that some types of food specifically increase density and some types build up biomass.

A study of ecological interactions (Anne Grace and Ismail, 1994; Anne Grace, 1996) reveals that *L. mauritii* increases both in biomass and population density when cultured in sand with suitable organic amendments. Maximum values (tables 2 and 3) of biomass and population numbers in sands are recorded about 80 days after the inoculation of earthworms in culture pots. Amendments with sawdust seems to promote numbers and paper seems to promote biomass.

Table 2: Biomass (g Mean ± SE) of L mauritii in sand with different amendments

Amendment	Day 0	Day 30	Day 80	Day 200
sand+cellulose +cowdung	8.110 ± 0.028	7.175 ± 0.124	21.820 ± l.287	24.085 ± 0.647
sand+hay +cowdung	7.550 ± 0.389	4.055 ± 0.499	3.125 ± 0.760	2.835 ± 0.477
sand+paper +cowdung	8.550 ± 0.354	9.370 ± 2.362	22.910 ± l.803	14.180 ± 2.234
sand+sawdust +cowdung	6.650 ± 0.212	3.765 ± 0.555	12.220 ± 0.544	2.135 ± 0.194
sand +cowdung	5.275 ± 1.397	7.030 ± 0.136	13.195 ± 0.187	0.830 ± 0.021

Biomass: 2.5 times increase in paper amendment on 80th day
1.8 times increase in sawdust amendment on 80th day

Table 3 : Population (Nos Mean ± SE) of L. mauritii in sand with different amendments

Amendment	Day 0	Day 30	Day 80	Day 200
sand+cellulose +cowdung	8 ± 0	14.0 ± 0.7	34.5 ± 1.1	47.5 ± 1.8
sand+hay +cowdung	8 ± 0	10.5 ± 1.8	7.0 ± 1.4	7.5 ± 0.4
sand+paper +cowdung	8 ± 0	57.5 ± 20.2	54.0 ± 13.4	45.5 ± 9.5
sand+sawdust +cowdung	8 ± 0	7.5 ± 0.4	76.0 ± 4.2	6.0 ± 0.7
sand +cowdung	8 ± 0	19.0 ± 2.8	34.5 ± 2.5	3.0 ± 0.7

Population: 9.5 times increase in sawdust amendment on 80th day
6.8 times increase in paper amendment on 80th day

Biochemical changes during growth

Remarkable changes occur during the growth stages of earthworms. The water content in the body of juveniles is about 70 per cent, 82 per cent in nonclitellates and 76 per cent in clitellates (table 4). A similar trend is seen in the protein and lipid contents. There are however no remarkable changes in the carbohydrate and ash contents of juvenile, nonclitellate and clitellate worms (Alawdeen and Ismail, 1986).

Table 4: Water, carbohydrate, protein, fat and ash contents of L. mauritii (Alawdeen and Ismail, 1986)

Stage	*% of water content in body*	*Carbohydrate*	*%mg dry weight Protein*	*Lipid*	*Asg*
J	69.30±8.30	0.90±0.26	45.50±6.20	15.60±0.80	6.13±0.12
NC	81.80±2.80	0.79±0.18	50.46±5.70	8.66±1.80	5.00±2.90
C	76.26±2.80	0.99±0.27	48.13±6.60	11.50±2.50	5.42±0.32

About 73 per cent of the body of *P. excavatus* is made up of water. Clitellates record more carbohydrates (6.6 per cent), the non-clitellates more proteins (30.72 per cent) and juveniles more lipids (0.85 per cent).

V

Earthworms : For Culture

> Organisms are not just 'slaves' to the physical environment; they adapt themselves and modify the physical environment so as to reduce the limiting effects of temperature, light, water and other physical conditions of existence. Such *factor compensation* is particularly effective at the community level of organisation, but also occurs within the species. Species with wide geographical ranges almost always develop locally adapted populations called *ecotypes* that have optima and limits of tolerances adjusted to local conditions. The possibility of genetic fixation in local strains has often been overlooked in applied ecology; restocking or transplanting of plants and animals may fail because individuals from remote regions are used instead of locally adapted stock.
>
> *Odum, E.P. (1971)*

Worms for vermiculture

Of the three ecological varieties of earthworms, the epigeics in particular and the anecics in general, have largely been harnessed for use in the vermicomposting process.

Epigeics like *E. fetida* (Hartenstein *et al.*, 1979 a, b) and *E. eugeniae* (Kale and Bano, 1988) have been used in converting organic wastes (agrowastes and domestic refuse) into vermicompost. Though these surface dwellers are capable of working hard on the litter layer and can convert all the organic waste into manure they are of no significant value in modifying the structure of the soil. The anecics, however, are capable of both organic waste consumption as well as in modifying the structure of the soil. Such burrowing species that are widely used in soil management like the earthworm, *L. mauritii* (Ismail, 1993) also effectively create a drilosphere apart from helping in compost production.

Of special significance are the use of local varieties of earthworms in vermitech* (Ismail, 1993). Ismail (1993) recommends the *in situ* soil community, especially earthworms comprising the epigeic and anecic varieties, for the combined process of litter and soil management.

It is apparent that a complex chain of interactions take place between the activities of different kinds of soil organisms. Of the several species of earthworms commonly available in Tamil Nadu (Ismail and Murthy, 1985; Ismail, 1986; Ismail *et al.*, 1990), Ismail (1993; 1994 a, b, c; 1995 a, b) recommends that though *P. excavatus* and *L. mauritii* together take care of the litter and other organic wastes, *L. mauritii* being an anecic earthworm also takes care of soil management by burrowing through it.

The advantages of using local varieties of earthworms are many. 'The hazards of using alien species are well known. History is littered with examples of confrontations between indigenous and foreign organisms' (Mac Kenzie, 1991). Kale *et al.*, (1982) have reported *P. excavatus* to be the Indian equivalent of *E. fetida*. It has however been observed that *E. eugeniae* and *P. excavatus* do not coexist comfortably in mixed cultures, indicating competition among the species of earthworms, probably for food (Abbott, 1980). The introduction of foreign species of earthworms (Stockdill, 1982) has time and again been justified by few scientists (Lavelle, *et al.*, 1989; Murphy, 1993) though it is extremely unnecessary and undesirable to tamper with the local biodiversity (Ismail, 1995 b).

Of the several species of epigeic earthworms used in vermicomposting, three species have been recommended and applied in laboratory and field situations. They are *P. excavatus*, *E. eugeniae* and *E. fetida*. Reinecke *et al.*, (1992) have worked out the suitability of these species of earthworms in vermicomposting in terms of their temperature requirements.

It is still necessary, and in fact, essential, to harness the potential of several epigeic and anecic species of local varieties of earthworms. These efforts will help in improving the soil faunal component of a given soil ecosystem. Some workers (e.g., Murphy, 1993) however, prefer imported worms to indigenous worms for improved pastures.

Worm-worked soils (Plate 9) are conspicuously different from soils devoid of earthworms. Importantly, the tunnels formed by the worms (Rahuman, 1984) aid in the passage of water which also washes the nutrients from the drilosphere to the roots that extend quite rapidly along these channels. This principle is also applied in the preparation of vermiwash*. Vermiwash functions as a good foliar spray, as it contains the requisite nutrients in it.

Worms, not only contribute their mite in providing valuable components to the plants when they are alive, but also contribute significant amounts of

nitrogen to the soil when they are dead. Since about 60 per cent of their bodies (dry weight) are made up of protein they release considerable nitrogen from this protein into the soil.

The passage of material through the earthworm gut converts the locked up minerals into available forms which are readily assimilable by plants. This is made possible by the presence of a large number of microflora in the guts of earthworms. Significantly, castings produced by earthworms have nearly hundred times more bacterial population than the surrounding soils.

Earthworm breeding

There are more than 500 species of earthworms in India (Julka, 1986). Many are yet to be identified and, more importantly, the potential of each of the species as well as their life cycles are yet to be worked out.

Worm breeders should be clear about why they are raising earthworms. If worms are cultured only for the sake of multiplying them for use in angling or in the process of waste digestion with rapid multiplication of earthworm biomass, then epigeic species of earthworms may be sufficient. However, these epigeic worms will offer no significant contribution to the in situ improvement of soils. In agricultural situations, where the motive is not just addition of compost but improvement of soil structure, a complement of anecic earthworms along with epigeics is essential. If epigeics can predominantly convert agrowaste and other organics into compost then the anecics not only assist in the conversion of organic debris into compost, but by virtue of making drilospheres can effectively convey the material to the plants. Additionally, their migratory activity (predominantly vertical) creates sufficient pore space and consequently leads to soil improvement.

Nature has created and differentiated earthworms into epigeic, anecic and endogeic species based on definite ecological and trophic functions in the respective soils. To select either one of these is improper in an ecological holistic approach the hological approach where nature is considered a black box* (Odum, 1971).

Technology, according to Odum (1971) is a two-edged sword; it can be the means of understanding the wholeness of human beings and nature or the means of destroying it. The most 'risky' tool we are handling and playing with today is genetic engineering in the name of biotechnology. This technology has already led to genetic manipulations and destruction of biodiversity by the creation and implantation of monoculture 'jungles' in the name of agriculture and silviculture. To justify their growth, human beings have been incorporating several fertilisers into the soil designed in chemical laboratories and to protect these 'weak manipulations' they have been fabricating pesticides of deadlier compositions.

Although production and decomposition occur simultaneously in nature, yet the balance is not exact (Vallentyne, 1962). To convey that earthworms alone are responsible for the decomposition process in the soil is inappropriate. Microbial decomposition involves a variety of organisms and a complicated network of exchanges and feedbacks which are yet to be fully understood. It is appropriate to mention that earthworms promote microbial populations, either by virtue of their own intestinal mechanisms or by their casts, serving as 'culture plates' for the development and multiplication of several strains of bacteria. These bacteria are beneficial for the decomposition process as well for converting nutrients into available forms for plants. Disturbances, especially anthropogenic, result in interfered ecosystems causing a set-back to the soil faunal diversity, thereby depleting soil organic matter and disturbing the synchrony* of nutrient cycles.

Of the several species of earthworms, those most popularly applied in worm farms are *E. fetida, E. eugeniae, L. rubellus and P. excavatus* (in alphabetical order). Of these *P. excavatus is* distributed all over – from the Himalayan mountains to the plains of south India. Their potential along with *Perionyx sansibaricus* in the utilisation of organic wastes (Kale *et al,* 1982; Murphy, 1993; Ismail, 1994 a, b, c; 1995 a, b) reveals that they are excellent worms which are to be found effective both in nutrient poor soils as well as in manures.

Several species of epigeics or decomposer worms occur naturally in India as well as in the world, but scientific work pertaining to their lifecycles and their efficiency in organic waste utilisation, unfortunately has been confined only to a few selected species, probably because people are no more interested in such studies.

Vermicompost

The compost prepared by using earthworms is called vermicompost. Vermicompost is a very important aspect of organic farming package today. It is easy to prepare, has excellent properties and is absolutely harmless to plants. While vermiculture is the culture of earthworms, vermicastings* are fecal matter released by earthworms. The bulk density of the soil, in anecic and endogeic earthworms is one of the important determining factors in cast production (Habibullah and Ismail 1985; Krishnamoorthy, 1989). Cocoons are usually found in abundance in fertile soils which have a good population of earthworms. It is not essential that the cocoons of all species of earthworms should enter diapause during unfavourable climatic conditions. Every species of earthworm has a different mechanism for tiding over the conditions of stress (drought, for example) in their respective environments. Hence, it is not necessary that dried vermicompost or vermicastings, of every species of

earthworm should have cocoons in them – only few species of earthworms produce cocoons which can withstand dry conditions.

Collecting local earthworms

Collecting local varieties of earthworms is a very simple and pleasurable job.

Identify garden soil in a shady spot, near organically maintained trees or near open culverts carrying organic wash water from domestic or restaurant kitchens where worms are generally noticed. Place handful lumps of fresh cowdung scattered over a one metre square area, followed by hay or leaf litter and cover the whole unit with an old jute cloth or jute bag. Keep the place moist by watering it regularly (not by flooding it with water). In about a fortnight's time both epigeic and anecic worms may be observed in that place. The transfer of worms should always be done with some quantity of native soil. This ensures survival and also passive inoculation of cocoons from the area of collection.

If this method of collecting earthworms is not very successful in the first attempt, then the application of one kilogram of jaggery and one kilogram of fresh cowdung dissolved in 20 litres of nonsaline water to that area once or twice a week attracts earthworms. (This will not work in areas where there are absolutely no earthworms).

Remember earthworms can be pets, treat them well... and they will respond well!

VI

Vermiculture and Vermitech

Most of our knowledge of earthworms is based on the Eurasian family Lumbricidae, which includes *ca* ten per cent of the total of *ca* 3000 species of earthworms. Some 15 lumbricid species have been spread by European man and are now well established throughout the temperate regions of the world. They are rare in tropical regions, mainly confined to small areas at high altitudes and the dominant earthworms of the tropics are representatives of the families Almidae, Kynotidae, Glossoscolecidae, Megascolecidae, Eudrilidae and Ocnerodrilidae.

Lee, K. E., (1983)

How to start vermiculture

The first step in starting vermiculture and composting units is to arrange for regular input of feed materials for the earthworms. These can be in the form of nitrogen-rich material like cattle dung, goat manure and pig manure. Such manure can be used either in the fresh form or after it has become old. Poultry manure should however be handled carefully when it is fresh because it contains toxic components. Other organic materials like agrowastes and kitchen wastes can also be used as long as they are properly treated to provide a desirable C : N (carbon : nitrogen) ratio. When material with a high carbon content is used, with a C : N ratio exceeding 40 : 1, it is desirable to add nitrogen supplements to ensure effective decomposition. Using only carbon material or material with a very high C : N ratio, like paper and soaked cardboards, may just fatten the worms. All organic inputs should be added only as a limited layer each time to a height of 5 to 10 cm as an excess amount will generate heat. Earthworms are nonthermophilic and when temperatures increase in composting units they have to either move away from composting beds or die.

The best resource for composting is locally available material. A vegetable grower or vendor can use rotting vegetables, a dairy farmer can use cattle dung, a farmer can use agrowaste, a person at home or at a restaurant can use kitchen waste, and so on. Experience has shown that in the absence of proper nitrogen input in the form of cattle dung or other nitrogenous supplements, trees like drumstick *(Moringa oleifera)* and subabul *(Leucaena leucocephala)* planted along the borders of composting units contribute enough nitrogen through their leaves which fall into the composting units.

Vermicomposting units in open fields may attract a large number of other organisms as well, due to the readily available organic matter, moisture and suitable temperature. Apart from a large number of useful microbes (protozoans, bacteria, actinomycetes, fungi) and microarthropods, the units may host visible meso and macrofauna like ants, millipedes, centipedes, slugs,

Fig 9 : A large number of organisms may be attracted to the vermicomposting unit

toads, birds, snakes, rats, mice and moles. Though the list is exhaustive it is not essential that they all should be present in every vermicomposting unit.

All the organisms that are attracted to the pit are not harmful. In fact, millipedes assist worms in the degradation process. However, organisms like big black ants, red ants, termites and centipedes may relish earthworm cocoons and dine on hapless young earthworms. Moles, which are fortunately not found in tropical and subtropical climates, are known to relish earthworms.

Homes and gardens can maintain their composting units in cement tanks or circular well rings with welded mesh plates at the base and on the top as a lid. This will keep birds, rats and moles away.

Domestic units may attract red ants. These may also feed on cocoons and young earthworms. By experience it has been found that a native decoction works well to keep these ants under check. This decoction contains a mixture of 20 litres of water, 100 grams each of chilli powder, turmeric powder and salt and a little soap powder. This should be sprayed around the unit on the soil, whenever desired, to keep the red ants under control. Neem oil (0.5%) may also be used. This does not affect the earthworms.

Smaller crates in homes may be placed on slender pillars (25–30 cm) to prevent rats and mice from entering the unit.

During vermicomposting, the wastes are processed into organic fertilizers. We must remember that at the same time we are also getting rid of organic solid wastes. Solid wastes are today considered one of the major sources of pollution in the human environment. Vermiculture and vermicomposting in fact help in solid waste management, where organic solid wastes are considered resources.

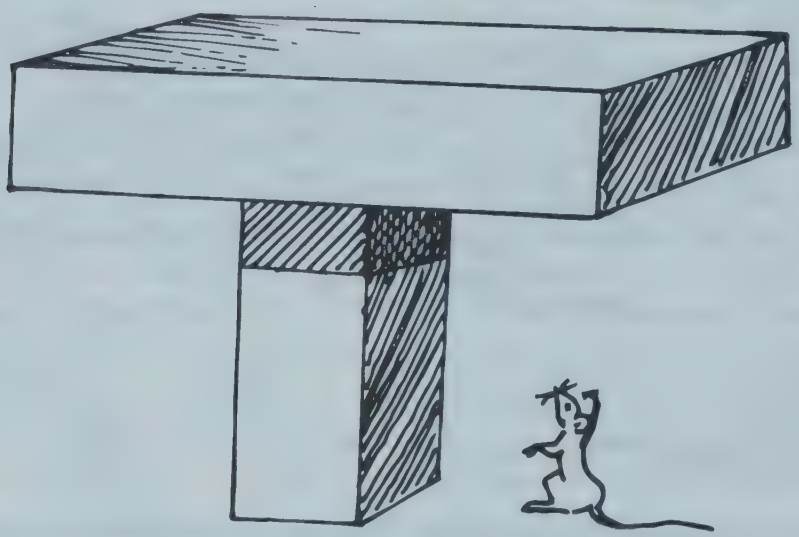


Fig 10 : Domestic compost unit placed on pillar or bricks

So the slogan worth remembering is: Do not waste waste, waste is precious.

Preparation of vermibeds*

While preparing vermibeds (Ismail, 1993) or worm beds, for epigeic species, soil is not required. However, if a combination of epigeic and anecic varieties are to be used as in agricultural situations, then it is advisable to have a base of not less than 15 cm of loamy soil. Composting can be done in pits, concrete tanks, well rings, wooden or bricklined grower beds, wooden or plastic crates or windrows* appropriate for a given situation.

It is very important to select the composting bed site carefully. A site under a shade, in an area on upland or an elevated level to prevent water stagnation in pits during rains, is ideal. In regions where rainfall is plentiful it may be preferable to avoid pits. However, in places like most parts of Tamil Nadu and Andhra Pradesh in India, where the annual rainfall is confined only to a few days in a year, the flooding of pits by rain does not cause much harm provided local varieties of earthworms are used.

The technology which uses epigeic and anecic earthworms together is called vermitech (Ismail, 1993). Vermitech (Fig 11A–I) is carried out by first placing a basal layer of a vermibed comprising broken bricks or pebbles followed by coarse sand to a thickness of at least 6 to 7.5 cm to ensure proper drainage. This is topped by a layer of soil up to a height of not less than 15 cm after it is moistened. Into this soil about hundred locally collected epigeic and anecic earthworms may be inoculated. (See collecting local earthworms in page 33). Small lumps of cattledung (fresh or dry pats) are scattered over the soil and this is covered with a layer of hay up to 10 cm in height. Water may be sprayed liberally till the entire set up is moist but not wet. The unit is finally covered with broad leaves like coconut or palmyrah fronds. This prevents birds from disturbing the vermibed. In case leaves or fronds are not available old jute bags may be used. A plastic covering should not be used as it traps heat and gases. Watering and monitoring of the unit should continue for thirty days. Juvenile earthworms should appear by this time which is a healthy sign.

Water management is the most important criteria in vermiculture as worms require moisture for their survival. Too little water kills the worms and too much chases them away. Water management, however, is simple and can be learnt as soon as one starts handling worms.

Organic refuse available from local resources should be added on the thirty-first day. It is important to remember that transferring resources from

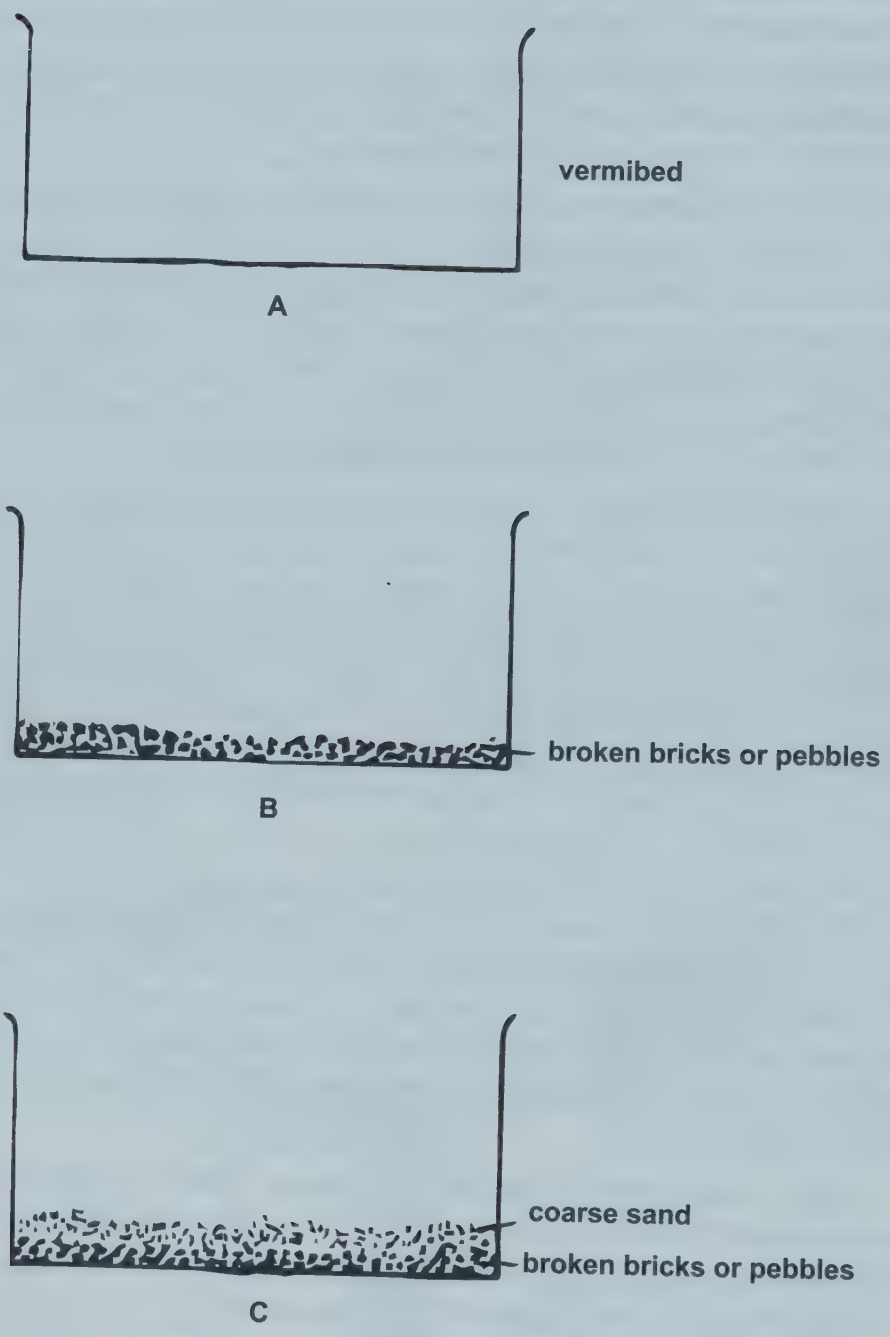
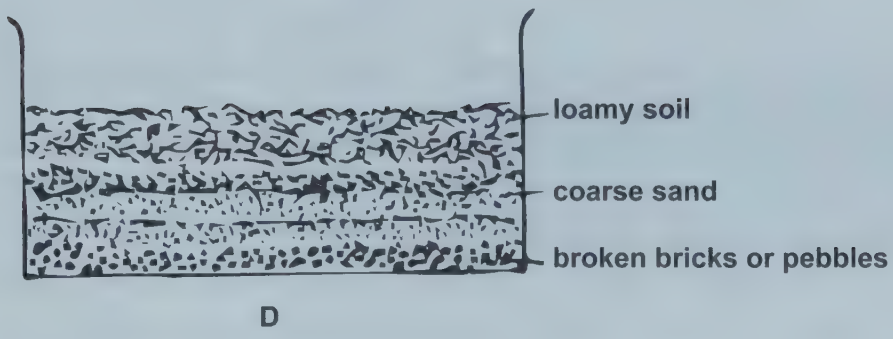


Fig. 11 (A, B, C): Setting up a vermicompost unit



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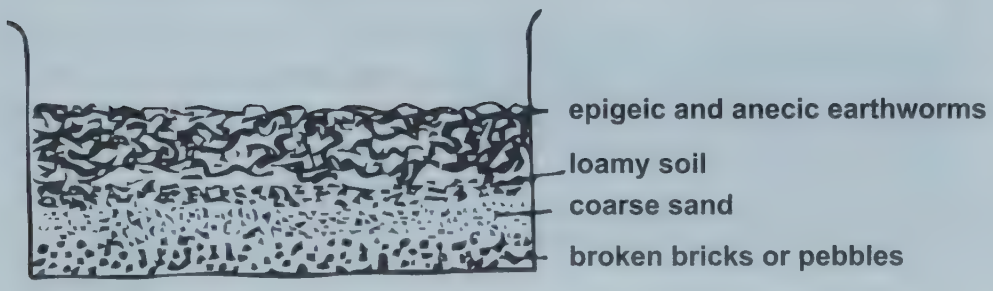

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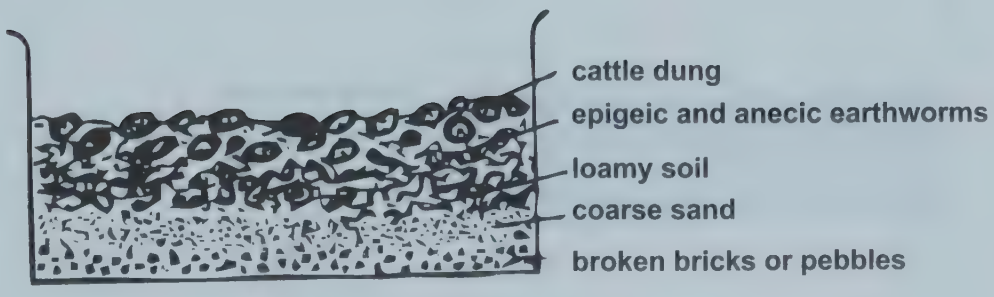

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Fig. 11 (D, E, F): Setting up a vermicompost unit

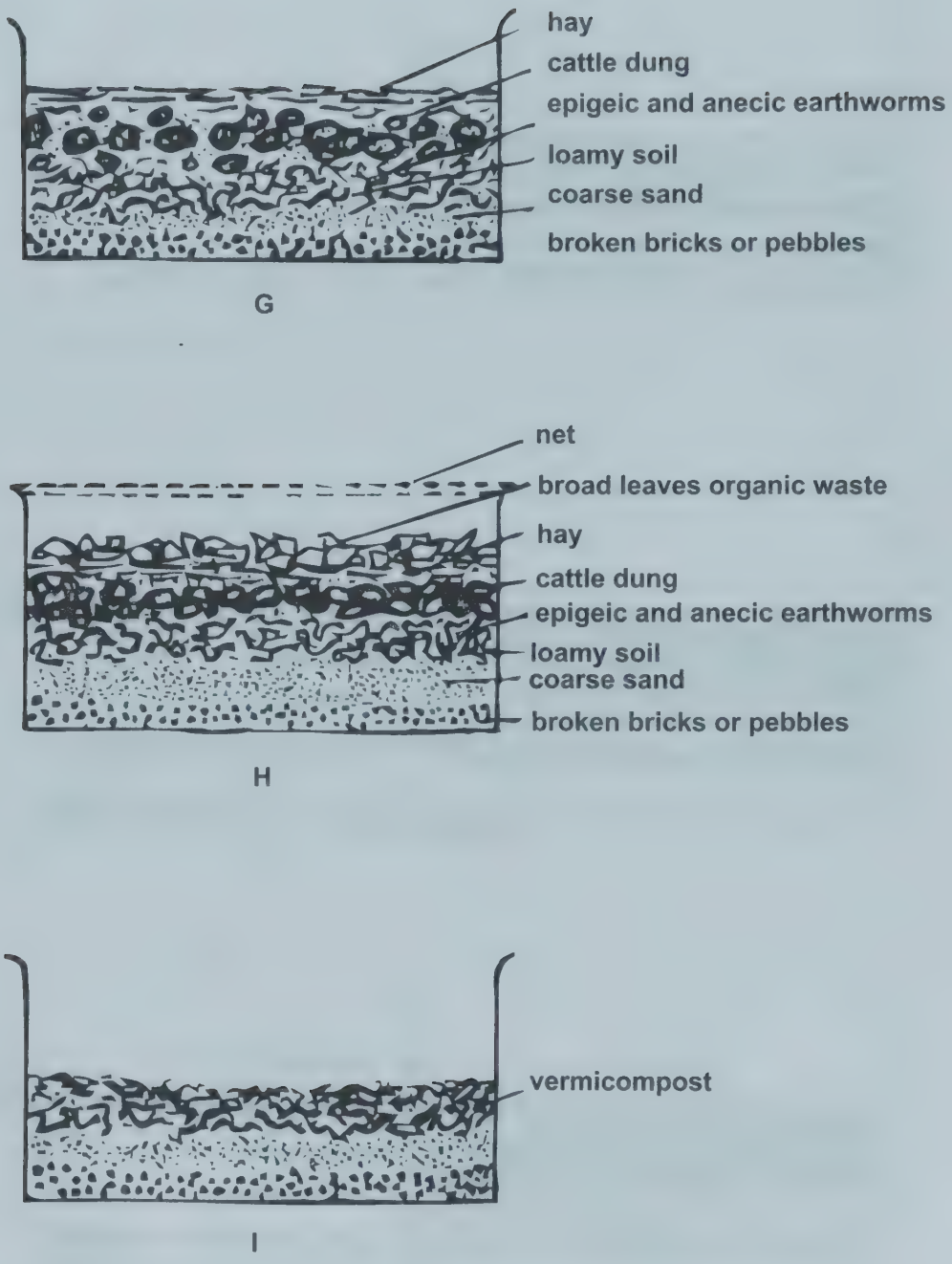


Fig. 11 (G, H, I): Setting up a vermicompost unit

other areas may be expensive and the cost of production of compost will eventually work out to be higher and uneconomical. This refuse should be spread on the bed after the fronds are removed. The spread should not exceed 5 cm in thickness for each application. Though addition of this amount of matter can be done every day, it is advisable for a beginner to spread this much of refuse only twice a week. Watering is continued according to requirement and the unit is still covered with fronds to keep birds away. After a few applications of the refuse, only the refuse should be turned over with a pitchfork taking care not to disturb the bed. When the refuse just fills the unit, watering is continued with occasional turning over of the refuse. Forty-five days after the last application of refuse, the compost is ready for harvest.

As the compost is getting ready (Plate 10) and the change of refuse into a soft, spongy, sweet smelling, dark brown compost is noticeable, adding of water can be stopped on the forty-second day. This compels the worms to move into the lower end of the vermibed and facilitates harvesting the compost without much damage to the worms. The harvested compost may be placed in the form of a cone on solid ground in bright sunlight. This further forces the worms still present in the compost to move to the lower layers. By spreading out the compost pile after about 24 to 36 hours, the worms from the lower layers of the compost can be recovered and may be later transferred to new composting units. If necessary, the compost, may be sieved through a 2 to 2.5 mm sieve and finally packed, preferably in polythene bags to retain its moisture.

For reasons of economy it is advisable to start a Twin Unit system. A time-table for such units each measuring 2 m x 1 m x 1 m is recommended in table 5.

Table 5: Effective time-table for proper harvesting of vermicompost through vermitech (twin unit system)

DAY	UNIT 1	UNIT 2
FIRST YEAR		
0	Vermibed	———————
30 days	Start loading	———————
45	———————	Vermibed
75	Stop loading	Start loading
120	(1) Harvest & cure	———————
125	Reload	Stop loading
165	———————	(2) Harvest & cure
170	Stop	Reload
215	(3) Harvest & cure	———————
220	Reload	Stop
265	———————	(4) Harvest & cure
270	Stop	Reload
315	(5) Harvest & cure	———————
320	Reload	Stop
365	———————	(6) Harvest & cure
SECOND YEAR		
370	Stop	Reload
415	(7) Harvest & cure	———————
420	Reload	Stop
465	———————	(8) Harvest & cure
470	Stop	Reload
515	(9) Harvest & cure	———————
520	Reload	Stop
565	———————	(10) Harvest & cure
570	Stop	Reload
615	(11) Harvest & cure	———————
620	Reload	Stop
665	———————	(12) Harvest & cure
670	Stop	Reload
715	(13) Harvest & cure	———————
720	Reload	Stop

This can continue.... The number of harvests is shown in parentheses.

If the freshly harvested, nonscreened compost, prepared with the help of any indigenous earthworm, is directly transferred to soils it will passively inoculate the worms, as freshly harvested compost most definitely contains cocoons and juveniles. In *situ,* the inoculation and maintenance of worms generally helps to multiply their numbers and improves ecosystems.

The same procedure described earlier can be followed in concrete tanks or rings with the facility for water drainage. Other methods like the windrow method or heap method are applied for vermiculture and vermicompost production when only epigeic worms like *E. fetida* and *E. eugeniae* are used.

Vermicomposting using exotic species of earthworms:

Exotic species of earthworms have also been used in India for vermicomposting. Internationally three species of earthworms have received acclaim for vermicomposting, they being *Eisenia fetida* and *Eudrilus eugeniae*, which are exotic, and *Perionyx excavatus*, which is endemic.

Since 1982 *E. eugeniae* has been promoted for waste degradation in India. *Eudrilus eugeniae* is reported to have surpassed both in feeding and reproductive rates compared to other species of earthworms. *Eisenia fetida* however is used in certain areas in India for domestic waste composting. After several experimentations the recommended method is as follows:

Fill the waste material into tanks followed by sufficient water to moisten the waste. The surface is then sealed with 25 mm thick layer of soil paste, and at every 300 mm distance, holes of 50 mm diameter are made and sticks are introduced into them for two days and are later removed. This provides the track for air circulation. The tanks can also have holes of 15 mm diameter all-round (walls) at 300 mm apart to provide cross ventilation. The well-aerated material does not emit any foul smell. After two weeks the earthworms are released on the soil surface. They enter into the organic matter and mix through the crevices left on the surface. The setup is left without disturbance for six weeks. Water is sprinkled occasionally on the surface during the composting process. The soil pack is then separated easily after two months, as these earthworms do not feed on the soil. The compost along with the earthworms is collected. In place of the mudpack, old jute (gunny) bags can also be used to cover the containers, but the bags themselves will get composted after some time. A crate (600 mm x 45 mm x 600 mm) can hold a population of 1500 adult *Eudrilus eugeniae,* and 3000 to 5000 *Eisenia fetida* and *Perionyx excavatus.* Frequent harvesting of *Eudrilus eugeniae* is necessary to reduce population pressure and enables continuous growth of earthworm population.

Four-Tank System:

To simplify the loading procedure for composting in rural sectors where the availability of organic material is not in bulk, a four-tank system can be set up based on a combination of biodung composting method and vermitech technique that enables continuous compost production using cattle dung produced daily at cattle sheds, weeds, leaf litter and other farm waste. A tank 4m x 4m x 1m (l x b x h) is made preferably under shade of tree. This is then divided into four equal parts with 22.5cm brick walls that have vents to facilitate aeration as well as migration of earthworms from one tank to another. This unit is designed especially for the small farmer who collects approximately 20 to 30 kg of cattle or farm waste per day. The schedule of loading the unit is described in the table below:

Schedule for a Four-Tank System

PERIOD (DAYS)	TANK	PROCESS
000-030	01	Collection of biomass and cattledung
030-060	01	Soaking of biomass with water, cattle dung slurry, and covering it with black polythene sheet. This could be called as biodung preparation
	02	Collection of biomass
060-090	01	Inoculation with earthworms
	02	Biodung preparation
	03	Biomass collection
090-120	01	Vermicompost ready and migration of earthworms from pit 1 to pit 2
	02	Vermicomposting
	03	Biodung preparation
	04	Biomass collection
120-140	01	Harvesting of compost and collection of biomass
	02	Vermicompost ready and migration of earthworms from pit 2 to pit 3
	03	Vermicomposting
	04	Biodung preparation

A four-tank system

Two-Tank System

In the same manner two-tank system for household garbage or less quantity of farm waste is recommended. This is a smaller tank 1m x 1m x 1m made above ground under shade. The tank is divided into two equal halved units vertically by a wall containing vents. An average family produces 250 to 500 gm of garbage that is added daily into one of the tanks. After a few days when a layer is formed 15 to 20 cm dry/green leaves and a thin layer of soil are made to cover it. Another layering of waste over a period of time follows this and it takes about two months for the tank to be filled. This is then covered with a black polythene sheet. The waste is now added to the second tank. The polythene sheet is removed after 15 to 20 days, allowed to cool for a day and about 150 to 200 locally collected earthworms are released into the biomass. It takes approximately 45 to 60 days for the biomass to be now converted into vermicompost. In the mean time the second tank gets filled and starts decomposing. The earthworms from the first tank by now start migrating into the second tank through the vents. The vermicompost is harvested from the first tank, which is now again ready for being filled.

The tank may be kept closed with a steel mesh cover to keep other animals away from damaging the set up. Out door plan requires about 10-20% more worms than the indoor method, as there are more predators and other climatic variables in the open tank system.

General composting

A compost heap can also be made layer by layer (Epstein, 1997). In the bottom layer, place twigs, stalks, hay, wood chips or other coarse material, which allows air to flow at the bottom. Follow with a layer of grass clippings (avoid grass if chemical pesticides have been used), leaves, manure, wood shavings, chopped weeds (picked before going to seed), vegetable and fruit scrapes, nut and eggshells. Sprinkle the material with water as you build the pile and repeat the sequence. The pile should be at least three feet high to trigger and sustain the required biological reactions. Do not let the pile get over five feet high, in which case the mass may pack down, squeeze out air and slow down decomposition. You can use a black polythene sheet to cover or alternatively use a jute sack as cover over the heap to retain the moisture. This is the set up for the Biodung method of composting.

Biodung can also be used as a predigestion exercise. Once cool (say after about thirty days), earthworms can be introduced into the heap to proceed with vermicomposting. For larger quantities of biomass it is always better to proceed through biodung composting before the inoculation of earthworms, whether local or exotic. This offers good results.

Several microorganisms occur during the biodung composting process. These include the fungi, bacteria, actinomycetes, and algae (Priscila 2004 Observations)

Fungi are the main agents of cellulose and lignin degradation, protein decomposition and humus formation. Among the fungi that were observed the *Penicillium sp* and *Aspergillus niger* possess properties to produce humus like substances. *Coprinus sp.,* is a basidiomycete and lignin decomposer. A few of the carbohydrate, cellulose and protein decomposers are *Aspergillus niger, Aspergillus fumigatus, Aspergillus flavus, Aspergillus terreus, Syncephalastrum racemosus, Trichoderma viridae,* and *Penicillium oxalicum.* Thermophilic fungi such as *Chaetomium thermophile, Mucor pussilus, Humicola griseus and Thermomyces sp* contribute to the breakdown of dead plant material and building of humus, when the temperature of the compost heap exceeds 40 °C; this is associated with microbial thermogenesis.

Bacteria play a vital role in the mineralisation of compost. Bacteria include the phosphate solubilisers, nitrifiers, nitrogen fixers and ammonifiers. The sulphur bacteria include the acid producing *Thiobacillus thiooxidans* and the sulphate producing *Thiobacillus thioparus.*

Actinomycetes constitute the breakdown of chitin and complex polysaccharides like cellulose and are found present throughout the biodung composting process. Some of the representative actinomycetes isolated include

the *Nocardia sp, Streptomyces sp,* and *Thermomonospora sp.*

Algae contribute to the nutrients and recycling of nitrogen. Most of the algae isolated from the compost pile are the blue-green algae comprising of heterocystous and non-heterocystous forms capable of fixing nitrogen. These include the *Westieliopsis sp, Anabaena sp, Microcystis aeruginosa, Chlorococcum humicolum, Oscillatoria sp and Tolypothrix sp.* A few green algae such as *Chlorococcum gigartinum, Chlorogloea fritschii, Desmococcus olivaceous* and a few diatoms *Pinnularia sp and Navicula sp* have also been observed.

As things stand now, vermiculture technology is all set to emerge as a big business of the next century. This versatile technique yields organic fertilizers, recovers energy rich resources, and makes for safe disposal of organic wastes and helps combat the spreading problem of environmental pollution. Today, many corporate units and business agencies are making a fortune by marketing vermicompost – an excellent soil conditioner – to the farmers and gardeners. India is still a long way behind in fully exploiting the promises of vermiculture technology for waste disposal and manure generation. With the amount of waste produced in India, the country could easily produce millions of tonnes of plant nutrients and considerably reduce the outflow of foreign exchange towards the import of fertilisers. Today, many industrial units covering sugar, paper, pulp and tanning make use of vermiculture technology for waste treatment.

What are the wastes that could be used for vermicomposting?

Agricultural waste: stubble waste, husk, straw, and farmyard manure. Stems, leaf matter, fruit rind, pulp and stubble. But be careful while handling an all-citric waste.

Animal waste: Dung, urine and biogas slurry. But be careful while handling poultry waste.

Urban solid waste: Kitchen waste from household and restaurants, waste from market yards and places of worship, and sludge from sewage treatment plants.

Agro industries: Food processing units: Peel, rind and unused pulp of fruits and vegetables, fine bagasse, pressmud and seed husk, stems, leaves and flowers after extraction of oil.

Industries: Sludge if free from heavy metals and other contaminants.

Vermiwash

Foliar sprays are a part of plant growing practices. Worm worked soils have burrows formed by the earthworms. Bacteria richly inhabit these burrows, also called as the drilospheres. Water passing through these passages washes the nutrients from these burrows to the roots to be absorbed by the plants. This principle is applied in the preparation of vermiwash. Vermiwash is a very good foliar spray.

Setting up of a vermiwash unit

Vermiwash units can be set up either in barrels or in buckets or even in small earthen pots. It is the principle that is important. The procedure explained here is for setting up of a 250 litre barrel.

An empty barrel with one side open is taken. Make a hole on the side and place a tap as seen in the picture (fig. 12). The entire unit is set up on a short pedestal made of few bricks to facilitate easy collection of vermiwash.

Keeping the tap open, a 25 cm layer of broken bricks or pebbles is placed. A 25 cm layer of coarse sand then follows the layer of bricks. Water is then made to flow through these layers to enable the setting up of the basic filter unit. On top of this layer is placed a 30 to 45 cm layer of loamy soil. It is moistened and into this are introduced about 50 numbers each of the surface (epigeic) and subsurface (anecic) earthworms. Cattle dung pats and hay is placed on top of the soil layer and gently moistened. The tap is kept open for the next 15 days. Water is added every day to keep the unit moist.

On the sixteenth day, the tap is closed and on top of the unit a metal container or mud pot perforated at the base as a sprinkler is suspended. Five litres of water (the volume of water taken in this container is one fiftieth of the size of the main container) is poured into this container and allowed to gradually sprinkle on the barrel overnight. This water percolates through the compost, the burrows of the earthworms and gets collected at the base. The tap of the unit is opened the next day morning and the vermiwash is collected. The tap is then closed and the suspended pot is refilled with five litres of water that evening to be collected again the following morning. Dung pats and hay may be replaced periodically based on need. The entire set up may be emptied and reset between ten and twelve months of use.

Vermiwash is generally diluted with water (10%) before spraying. This has been found to be very effective on several plants. If need be vermiwash may be mixed with cow's urine and diluted (one litre of vermiwash, one litre of cow's urine and eight litres of water) and sprayed on plants to function as an effecting foliar spray and pesticide.

The casts formed on the surface of the unit may periodically be cleared and cattledung pats and hay be replaced. Vermiwash can be collected and stored as such, or can be solarised, condensed and stored. This may be diluted before use, with a dilution factor that best suits the user. When the soil within the unit becomes excessively rich with organic matter and the earthworm density appears to dwindle, dismantle and reset the unit with fresh soil as before. The soil removed from the unit can however be used as manure for nurseries.

The valuable contribution made by earthworms to soil fertility has only very lately been recognised but there is yet a great deal to learn on soil management from the lowly earthworms.

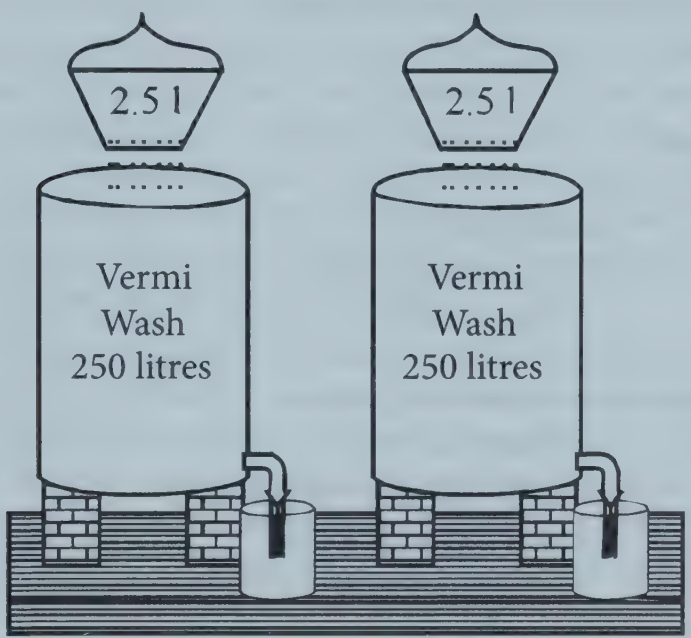


Fig.12: Setting up a Vermiwash Unit

Two barrels of 250 litres each can produce minimum of five litres of vermiwash every day after the 20th day of commissioning

ECONOMICS OF VERMITECH (In Indian Rupees)
Construction and maintenance of a TWIN UNIT SYSTEM

PRODUCTION CAPACITY			
Total surface area of production			
(2 m x 1 m x 1 m per unit)	2 units	=	4 sq m
Annual targeted production capacity	1500 kg x 2	=	3000 kg
Duration of each run (average per unit)		=	120 days
Number of harvests of compost/year	3/unit x 2	=	6 approx

FEASIBILITY REPORT	
Estimated capital investment	
Vermitech units	
Brick and mortar with shade made of sheets	27,000
Vermibed	1,000
Implements	1,000
Contingencies	1,000
TOTAL	**30,000**
a) Fixed costs	
i) Depreciation @ 10 %	3,000
ii) Interest @ 12%	3,600
	7,000
Total fixed costs approximately Rs. 7,000 only	
b) **Variable costs**	
Cost of inputs @ Rs. 400/ produce	2,400
Labour 2 hr/day @ Rs. 9/hr	1,650
Harvesting & packing @ Rs. 200/harvest	1,200
	5,250
Total variable cost approximately Rs. 6,000 only	

COST RETURN ANALYSIS	
1. Total cultivable space	4 sq m
2. Estimated production (minimum)	3000 kg
3. Sale revenue (@ Rs. 10/kg)	Rs.30,000
4. Total fixed cost	Rs.7,000
5. Total variable cost	Rs.6,000
6. Total cost (4 + 5)	Rs.13,000
7. Profit (3–6)	Rs.17,000
8. Total capital investment	Rs.30,000

(Footnote: The author is grateful to Deepak Suchde, Yusuf Meherally Centre, Panvel, India for introducing the concept of vermiwash to him.)

Pay Back Period (8/7)	=	1.76 yr (say, 2 years)
Cost of production per kg (6/2)	=	Rs. 4.33 (say Rs. 5)

(A minimum of six harvests can be made in the first year. A minimum of seven to eight harvests can be made subsequently after the first year. With proper management, the cost of production will also be reduced appreciably at the same time the duration and quantity can be improved.)

Marketing

Marketing vermicompost is now a potential and flourishing industry due to the growing awareness among the people about the ill effects of chemical fertilisers and the relative benefits of organic farming. The cost of vermicompost ranges between (Indian) Rs.2000 to Rs.5000 per ton of compost. The retail market in urban areas is more promising with the sale price of vermicompost, in neatly designed and printed packets, fetching rates as high as Rs.15 per kg. One of the pioneers in making vermicompost a commercially viable industry in India have been BERI in Pune. Today young people are involved in producing and selling vermicompost in several centres in India. For a kitchen garden or for growing ornamental plants, the compost prepared at home is sufficient and will not only serve as excellent manure but will also save money usually spent on fertilisers.

Unfortunately, the sale of earthworms as such has not been very promising in India so far as the desire for angling as a game is not as popular as it is in the west. However, worms like *E. fetida* and *E. eugeniae* are sold by agencies in the Indian markets especially in Pune and Bangalore (India). In India, *L. rubellus* also has a market. Worms may fetch a fancy price depending on the desire of a person to pay for them. We generally use local varieties of worms extensively to discourage the sale of exotic species.

It should be realised that vermiculture and vermicomposting can be a useful cottage industry for the underprivileged and the economically weak as it can provide them with a supplementary income. Several self help groups are now taking this as a microenterprise. If every village can formulate a cooperative society of unemployed youth, it could be a wise venture for them to produce vermicompost and sell it back to the village at a reasonable price. The youth will not only earn money, but also aid society by providing excellent quality organic manure for sustainable agro-practices. Moreover, with garbage recycled, the surroundings will be kept clean and tidy, which is a formidable task at the best of times for any organisation to cope with.

The only reservation against commercial exploitation of this compost is that no yardstick has been established as yet to evaluate the quality of the compost produced. As the compost is largely getting recognised and accepted,

independent research institutes in every zone in India (east, west, north, south and north east) could be authorised with clearly defined parameters to evaluate and certify such organic fertilisers. Otherwise, soil mixed with dried dung mixtures will soon flood the market in the name of vermicompost.

VII

Experiments from the Field

> The pattern of nutrient cycling in the tropics is, in several important ways, different from that in the temperate zone. In cold regions, a large portion of organic matter and available nutrients is at all times in the soil or sediment; in the tropics a much larger percentage is in the biomass and is recycled within the organic structure of the system. For this reason the agricultural strategy of the temperate zone, involving the monoculture of short-lived annual plants, may be quite inappropriate for tropical regions. An ecological re-evaluation of tropical agriculture in particular, and environmental management in general, is urgently required if man is to correct past mistakes and avoid future disasters as he quite literally 'bulldozes' his way into the jungles seeking more food and living space.
>
> *Odum, E.P, (1971)*

Earthworms: Their effect on plant growth

There is ample evidence to prove that earthworms act on litter and the absence of earthworms in an area is characterised by the presence of litter mats on the soil surface (Richardson 1938; Raw, 1962;. Hoogerkamp *et al.*, 1983; Ismail, 1983). Moreover, soils inhabited by earthworms have surface casts ranging from about 133 tons dry weight ha^{-1} yr^{-1} in grasslands to about 98 tons dry weight ha^{-1} yr^{-1} in woodlands. Maximum production however occurs during the wet periods (Dash and Patra, 1979; Krishnamoorthy, 1985). Hoogerkamp *et al.*, (1983) have shown from infrared, line-scanning, aerial photographs that earthworm-inoculated areas are warmer at night and cooler during the day than the surrounding earthworm free areas. Soil fertility results from

the maintenance of soil conditions such that the decomposition processes operate at levels adequate to release plant nutrients from the litter at a rate that sustains optimum growth (Maldague, 1970). Hoogerkamp *et al.*, (1985) also distinguish between the inherent mineralogical fertility, which owes its source to the parent material of the soil, and biological fertility, which relates to the decomposition of organic material. These two conditions operate simultaneously in soils. Soil organisms are among the agents for biological fertility and among the soil organisms which contribute to soil fertility, earthworms are the most important.

Darwin (1881) stated, 'earthworms prepare the ground in an excellent manner for the growth of fibrous-rooted plants and for seedlings of all kinds'. When earthworms are available in soils they always promote plant growth (Wollny, 1890; Hopp and Slater, 1948, 1949; Waters, 1951; Atlavinyte *et al.*, 1968; Springet and Syers, 1979; Edwards and Lofty, 1980). Van Rhee (1965) has reported that the production of grass, wheat and clover increases manifold in the presence of earthworms, while an increase in crop growth (Ponomareva, 1952), growth of maize (table 6) (Spain *et al.*, 1992) and ornamental plants (Kale *et al.*, 1987) has also been reported.

Table 6: Effects of earthworm treatments on the survival and growth of maize plants (Spain et al., 1992)

Species	Earthworm live biomass added per Pot	Plants surviving to harvest	Mean earthworm biomass at harvest	Mean plant biomass at harvest	Ratio root: above ground biomass
	g		g	g	
Control	0	1	0.00	1.19	0.88
H. africanus	2	2	0.01	1.05	0.30
P. corethrurus	2	3	0.00	1.74	0.30
M. anomala	1	2	1.20	3.02	0.17
M. anomala	2	3	1.00	1.30	0.25
M. anomala	5	2	0.27	2.79	0.44

The beneficial effect of earthworms on plant growth may be due to several reasons apart from the presence of macronutrients and micronutrients in vermicasts and in their secretions in considerable quantities. There are reports that certain metabolites produced by earthworms may be responsible for stimulating plant growth (Gavrilov, 1962; Nielson, 1965). It is believed that earthworms release certain vitamins and similar substances into the soil

which may be the B group vitamins (Gavrilov, 1963), or some provitamin D (Zrazhevskii, 1957), or free amino acids (Dubash and Ganti, 1964). The amount of vitamin B is generally known to double itself twice within a year or two after the introduction of these worms (Daciulyte, 1969; Atlavinyte *et al.*, 1971).

Though the NPK (Nitrogen Phosphorus Potassium) value of the vermicast is always lower than that of any standard chemical fertiliser (Tomlin, 1983), several experiments (Keshavamurthy, 1978; Reinecke and Visser, 1980) have proved that wormcasts can promote lush growth of plants. This may be due to the presence of plant growth promoters like cytokinins and auxins (table 7) in casts (Krishnamoorthy and Vajranabhaiah, 1986). There is however, a gradual loss of plant growth promoter activity over a period of time (table 8) as they are photolabile and relatively unstable *in vivo* as well as *in vitro* systems (Sembdner *et al.*, 1980).

Table 7: Rate of plant growth promoter output by two tropical earthworms (Krishnamoorthy and Vajranabhaiah, 1986)

Species	Rate of production (**nanograms day $^{-1}$ worm $^{-1}$**)	
	cytokinins[b]	auxins[c]
Wormless control soil	nil	nil
Lampito mauritii	4.3 ± 0.016 (5)	54 ± 6 (5)
Perionyx excavatus	78.1 ± 0.520 (6)	316 ± 21 (6)

[a] Number of experimental observations in parenthesis

[b] Benzyladenine equivalents

[c] Indol acetic acid equivalents

For effective utilisation of the soil ecosystem in agropractices, the maintenance of vermicompost-earthworm-mulch-plant root (VEMP*) interaction is a must.

Table 8: Loss of plant growth promoter activities in wormcasts of L. mauritii on aging under constant moisture and dark conditions at room temperature (26± 2 °C (Krishnamoorthy and Vajranabhaiah, 1986)

Weeks after casting	Loss of activity with reference to initial level (%)	
	cytokinins	auxins
0	0	0
1	2	1.5
2	4	4
3	9	7
4	15	18
5	26	21
6	35	34
7	47	41
10	69	58

Application of green manures like *Sesbania rostrata* in organic farming is today becoming essential. The possibility of interaction of the root hairs of these plants with nitrogen fixing organisms may be increased by the VEMP interaction. Green manuring depends on the rate of nutrient transfer to plants and it will be a distinct advantage if such an interaction is enhanced. The age of the green manure crop to be ploughed in (Ramakrishnan and Rangarajan, 1993) correlates with the VEMP interaction. It is well known that earthworms prefer lower levels of lignin and tannin, and in case of green manuring, younger plants are recommended for ploughing in for an effective release and uptake of nutrients.

Vesicular Arbuscular Mycorrhizae (VAM*) are effective in cases of wheat and other crops (Verma, 1993). The population of VAM is enhanced in the presence of earthworms (Kale *et al.,* 1992) as earthworms are vectors of viable propagules (spores) of VAM (Reddell and Spain, 1991). The uptake of phosphate is facilitated by VAM, and conservation of such microbes is facilitated by earthworms.

The application of vermicompost is recommended in a manner similar to chemical fertilisers, that is, based on soil analysis where the NPK of the soil and the compost is taken into consideration. Again, the application of vermicompost varies according to prevailing crop factors (for example, the time of application). The nutrients present in vermicompost are readily available and the increase in earthworm populations on application of vermicompost and

mulching leads to the easy transfer of nutrients to the plants, thus providing synchrony in ecosystems which have been interfered with. The availability of nutrients in soils tilled by earthworms is mainly (Robinson *et al.,* 1992) due to the formation of drilospheres. Vermicompost, therefore, without doubt has tremendous potential for ensuring a good yield; the yield however depends on the management practices followed by the farmer.

A staggered application of vermicompost in the case of paddy, at the time of tillering, panicle initiation, flowering and grain filling is essential. In the case of VEMP interaction, the loss of nutrients by leaching and other phenomena related to nutrient loss is minimal as compared to the reaction seen when chemical fertilisers are used.

It is advisable to apply a top dressing of vermicompost, apart from basal applications of vermicompost, as it helps to retain sufficient moisture which will, in turn, minimise loss of compost on application and also avoid dispersal by wind.

Pelletising of vermicompost is a good alternative to work on, as pelletised or granulated fertilisers are now entering the market and are being accepted for several reasons, some of these being, easy application, minimal loss of fertiliser on application and the gradual leaching of nutrients over a period of time. Pelletised feed for plants is today as acceptable in agriculture as pelletised feeds for fish and shrimps is in aquaculture. Since there is waterlogging in paddy cultivation, it is recommended that vermicompost is applied when the water level is minimal on the soil surface. The presence of earthworm burrows in the soil facilitates transfer of nutrients to the rhizosphere. In systems where *Azolla* is applied as an organic input, the decomposition and release of nutrients may be hastened by the application of vermicompost. The effectiveness of adding blue-green algae along with vermicompost is not as well understood as compared to the use of other biofertilisers. Foliar sprays such as vermiwash, Panchgavya*, EM (effective microorganisms), singularly and in combinations help a lot in plant growth and yield.

In sugarcane, paddy and other crops, vermicompost can be effectively utilised as a carrier medium for *Azospirillum, Rhizobium* and phosphate solubilisers which are recommended along with FYM* (Farm Yard Manure). Moreover, these provide a very good association for enhancing their interactions with plant roots. In sugarcane cultivation application of vermicompost is recommended. This enhances accumulation of sugar in the cane as observed in experiments conducted at the *Biovillage Project,* Pondicherry in collaboration with the M. S. Swaminathan Research Foundation (Plate 12).

Coir pith is being widely used for orchards and other horticulture crops, because of its water holding capacity especially in semiarid areas. This practice is supplemented by chemical fertilisers at present and the shifting over to organic cultivation has influenced the farmer to use coir as a mulch. Yet another organic waste from the sugar industry in the form of pressmud is very suitable in VEMP interactions. The release of nutrients is probably enhanced because of the abundance of earthworms present due to the application of vermicompost. Though in most cases the root systems grow deeper, unlike field crops, there may be doubts about earthworm interactions with roots of trees. Endogeic earthworms (Lavelle *et al.*, 1989) and the anecic earthworms (personal observations) have been found to certainly promote plant growth.

Growing vegetables

The fact that soil health and crop production are related to one another has time and again been reiterated. Health of the soil improves the quantity, quality and health of the agricultural produce. Experiments conducted on the effect of earthworms and/or vermicompost on the cultivation of vegetables like tomato, brinjal and okra have yielded very valuable results (table 9). A series of experiments conducted in collaboration with the Auroville Greenwork Resource Center, on the growth of vegetables in field situations using different organic fertilisers, have clearly indicated that the presence of earthworms enhances productivity and soil fertility.

Table 9: Comparative parameters of growth in vegetable using (a) FYM (b) Vermicompost and (c) Vermicompost + Earthworms

	AVERAGE FRUIT (Okra)			
Parameters	weight/ harvest (g)	number/ harvest (g)	length at harvest (cm)	circumference at harvest (cm)
a) FYM	163.66	7.73	14.67	6.37
b) vermicompost	207.66	9.06	16.76	9.60
c) vermicompost+ earthworm	230.33	25.55	17.84	7.14

To illustrate the merits of this technology, vegetables grown under various organic conditions have been exposed to Kirlian photography. Shelf life is of great importance in the marketing of fruits, flowers and vegetables. Experiments with Kirlian photograph also throw light on the 'keeping' quality of these vegetables.

Fig 13a : Growing Okra

Fig 13b : Growing Okra

Fig 13c : Growing Okra

It is of interest to observe living tissue by Kirlian Photography. Okra grown on chemical fertilisers and those grown on vermicompost and vermicompost along with live earthworms in the soil were exposed to Kirlian photography (Figs 13a, b and c). It is evident from these figures that the patterns created by these vegetables on the day of harvest and the week after harvest reflect their keeping quality. Due to lack of proper software with us (Edward Giordano's and Sultan Ismail's teams) computerized numerical ratings of these Kirliograms could not be accomplished.

Are earthworms alone?

Earthworms are only one of the numerous range of burrow organisms which improve soils (Pereira, 1993). Fertile soil harbours bacteria, fungi, actinomycetes, protozoans, proturans, symphylids, pauropods, spring tails, pseudoscorpions, insects and their larvae, millipedes, centipedes, slugs, snails, snakes, rodents and earthworms. This fauna along with diverse flora contribute to soil quality. Among the meso and macro fauna, earthworms seem to be the most soft-bodied animals living in the soil. Others either have a thick cuticle or some form of exoskeleton or protective device for their defense in the rather difficult subterranean ecosystem. So, the presence of earthworms in soils is indicative of the presence of other faunal representatives contributing to soil fertility. Earthworm species in a particular soil can also be indicators of the soil type and its properties (Müller,1878; Lee, 1959; Ghilarov, 1965; Kaleemurrahman and Ismail, 1981). It would therefore be certainly appropriate to describe the earthworm as an indicator of soil health and referred as the 'pulse' of soil health. Healthier the pulse, healthier the soil.

Effect on soil quality

Soil quality is affected by soil aggregates and these aggregates often determine the retention and movement of water, diffusion of gases, growth and development of roots in the soil (Ghildyal and Gupta, 1991) and also provide large surface areas to which plant nutrients adhere (Reganold *et al.*, 1990). The capacity of the soil to hold such nutrients is an indication of the potential fertility of the soil (Pereira, 1993).

Soil organic matter is an essential component of the soil and, in association with the soil fauna, contributes to soil fertility. Soil faunal density and diversity is also partly due to the desired C : N availability in soils. Mulching promotes and supports the density and diversity of a wide range of soil organisms. Sources of carbon in the form of cellulose, for example, are mainly contributed by plants and hence forests have a natural mulch cover during the fall to protect the soil and its inhabitants for the rest of the seasons. Mulching also has the added advantage of keeping the soil cool, thus preventing

evaporation and erosion. According to Edwards and Lofty (1977), earthworms seem to consume very large amounts of litter, and the amount they turn over seems to be more dependent on the total amount of suitable organic matter available rather than on other factors.

If the physical soil conditions are suitable, the number of worms usually increase until food becomes a limiting factor. The C : N ratio of freshly fallen litter is greater than 20 : 1. During the process of litter breakdown and decomposition, the ratio of C : N is progressively brought down, especially through feeding by the earthworms to levels when nitrogen can be directly taken up by plants (Edwards *et al.*, 1970). The disappearance rate of litter is higher in microcosms inoculated with earthworms associated with increase in earthworm biomass (Binet and Trehen, 1992; Chitra and Ismail, unpubl. data). Earthworms also influence the net production and nitrogen content of birch seedlings (Haimi *et al.*, 1992). In the humid Savannah soils, macrofauna is largely composed of geophagous species like termites and earthworms which feed on soil organic matter (Athias *et al.*, 1975).

At least a part of the produce from the field should go back into the ecosystem in the form in which it was drawn out, that is, in the organic form. A great amount of paddy straw, for instance, is used in practices unrelated to agriculture instead of being reused as mulch for improving soil dynamics. The concept of live mulching, that is, covering exposed soil by growing green plants as intercrops is one of the most advantageous concepts being used in recent times. Intercropping with leguminous plants contributes nitrogen to the soil. Weeds have always been considered as pests, leading to the practice of weed control, weed removal and weedicides, with undesirable consequences. The concept of weed utilisation must replace weed control. Several organic farmers in India have proved this on field.

It is indeed interesting to apply Intensive Integrated Farming Systems which recommend utilising several types of crop and animal husbandry-interlinked systems as traditionally practised by farmers in India and other countries, especially in the tropical belt. Such systems keep the soil enriched through manure from the livestock, which also supports earthworms and the rest of the soil community which in turn contributes to soil health. Moreover these local resources enable farmers to prepare "*potions*" such as Panchagavya* on farm.

Soil loss

It takes several years for good soil to be built up. Any faulty soil management practice can cause loss of top soil and it takes several years to rebuild the lost soil. One of the major causes of soil loss is erosion. Though several mechanisms have been implemented to prevent erosion, one of the important organisms which prevents soil erosion by reducing runoff is the earthworm (Hopp, 1946). Much erosion occurs because of deforestation and cultivation or overgrazing of sloping lands. Erosion, could to a large extent, be controlled by restoring ground cover and developing live hedges.

As it has already been proved that earthworms aid in soil fertility, attempts have been made to ameliorate poor soils using earthworms. This seems particularly promising in reclaiming flooded areas that are subsequently drained and put into cultivation (van Rhee, 1969, 1972), and in newly established areas of artesian irrigation (Ghilarov and Mamajev, 1966). The species of earthworm selected should however be appropriate.

It is well established that tillage in agroecosystems adversely affects earthworm communities (Edwards, 1983; Lee, 1985; Parmelee and Crossley, 1988). By using organic inputs, however, large earthworm populations can be maintained in agricultural lands (Binet and Trihen, 1990; Mohan *et al.*, 1995; Ismail, unpubl. data).

Vermiwash, a liquid fertiliser collected after the passage of water through a column of worm action is very useful as a foliar spray. It is a collection of excretory products and mucus secretions of earthworms, along with micronutrients from the soil organic molecules. Vermiwash, if collected properly, is a clear and transparent, pale yellow coloured fluid, whose physicochemical characteristics are given in table 10.

Table 10: Physicochemical characteristics of vermiwash – analysis report

pH	7.48 ± 0.03
Electroconductivity dS/m	0.25 ± 0.03
Organic Carbon %	0.008 ± 0.001
Total Kjeldhal Nitrogen %	0.01 ± 0.005
Available Phosphate %	1.69 ± 0.05
Potassium (ppm)	25 ± 2
Sodium (ppm)	8 ± 1
Calcium (ppm)	3 ± 1
Copper (ppm)	0.01 ± 0.001
Ferrous (ppm)	0.06 ± 0.001
Magnesium (ppm)	158.44 ± 23.42
Manganese (ppm)	0.58 ± 0.040

Zinc (ppm)	0.02 ± 0.001
Total Heterotrophs (CFU/ml)	1.79×10^3
Nitrosomonas (CFU/ml)	1.01×10^3
Nitrobacter (CFU/ml)	1.12×10^3
Total Fungi (CFU/ml)	1.46×10^3

The utility of vermiwash in aquatic productivity (Ismail and Pramoth, 1995) is immense (table 11) but its potential as a biocide, either singly or when mixed with botanical pesticides, is still under investigation. The vermiwash complex is efficient in raising of nurseries, lawns and orchids. 10% vermiwash has proved to be very effective either singly or in combination with diluted Panchagavya and/or EM solutions (Thangaraj, 2003 observations)

Table 11: Productivity (ml l^{-1} hr^{-1} in pond water fertilised with vermiwash (Laboratory experiments using light and dark bottles)

Sample	Gross Primary Production	Community Respiration	Net Primary Production
Pond water	0.151	0.192	nil
Vermiwash 10%	0.454	0.227	0.226
Vermiwash 25%	0.227	0.114	0.112
Vermiwash 50%	0.645	0.190	0.455

Adverse effects on crops

Earthworm activity is also reported (Walton, 1928) to damage crops by either seizing fallen leaves of live plants and pulling them down (Zicsi, 1954) or by uprooting delicate seedlings (Barrion and Litsinger, 1993). Casts may show up as ugly structures in ornamental lawns or may form an unnecessary obstruction on golf courses (Schread, 1952) or football pitches (Piearce *et al.*, observations). Earthworms have also been accused of being responsible for transmitting many parasitic diseases in plants and animals (Edwards and Lofty, 1972). They are reported as being the vectors of the foot and mouth disease of domesticated animals (Dhennin *et al.*, 1963) and in most other parasites, earthworms are reported to be just passive agents or reservoir hosts.

Impact of chemicals on earthworms

A large number of pesticides used in agriculture are known to adversely affect earthworm populations resulting in an imbalance of the normal functioning of the various components of the ecosystem. The effect of Sevin on the survivability and numbers of earthworms (Kale and Krishnamoorthy,

1979) and on AChE activity (an enzyme) (Kale and Krishnamoorthy, 1982) has been reported.

Several authors (Bharathi and Subba Rao, 1984 a, b, 1986 a, b, and 1987; Gupta and Sundararaman, 1987, 1988 a, b, 1991; Hans *et al.,* 1993, 1994; and Senapati *et al.,* 1987;) have worked on aspects pertaining to the role of pesticides on the life of earthworms. There is a pronounced effect of pesticides on non-targets organism like earthworms.

Because of the growing awareness about organic farming and sustainable agriculture it is essential to replace chemical biocides with biocides of plant origin. It is observed, for example, that neem cake which is used as a pesticide does not adversely affect earthworm populations (Kale *et al.,* 1986). Moreover, neem leaves seem to be preferred by earthworms (Chitra *pers comm*).

Impact of heavy metals

Heavy metals enter plants not just through the roots but also by aerial absorption (Hughes *et al.,* 1980). Since earthworms have a preference for leaves (Piearce, 1978), they may accumulate heavy metals in their tissues irrespective of the quantity of heavy metals present in soils (Ireland, 1983). Earthworms may act as biomagnifiers and transfer the metals in their tissues to higher organisms through the food chain. A modified continuous flow respirometer had been designed (Joseph *et al.,* 1992) to measure oxygen uptake by earthworms in the presence of pollutants.

Earthworms in food chains

The abundant food resource in the form of earthworms is utilised by diverse predators and for some organisms it is the principal food (Macdonald, 1983). Earthworms are preferred as feed by amphibians (Lescure, 1966), reptiles (Catling and Freeman, 1980), birds (Harlin, 1977) and mammals (Hamilton, 1930; Churchfield, 1979) among the vertebrates, apart from fishes which fall prey to the worm on the hook. Among invertebrates, centipedes may comfortably feed on cocoons or hapless earthworm juveniles.

With the worm now fighting for a place on the dining table, in the form of earthworm soups, vermiburgers and patties and with the immense potential of earthworm in medicine, it is essential to check the bioaccumulation of heavy metals in earthworms.

Earthworm parasites

A few representatives of protozoa, platyhelminthes, nematoda and dipteran larvae may be parasites on earthworms.

It has been reported that a New Zealand planarian flatworm *Artioposthia triangulata,* had been eating up earthworms and spread fast across Ireland and Scotland (MacKenzie, 1991). This flatworm wraps itself around the earthworm and secretes powerful digestive enzymes on it. It then sips the liquidised victim through the slit-like mouth on its underside. This parasite has the potential to cause an epidemic of sorts which may lead to eliminating earthworms from soils altogether. The chief reasons attributed to the presence of these flatworms in Scotland is the inadvertent import of potted plants from New Zealand to this country. These probably might have contained flatworm eggs in the soil. Thus, as can be gleamed from this example, transfer of organisms of any kind (flora and/or fauna) can directly or indirectly cause irreparable damage to local biodiversity.

VIII

Earthworms: Their Applications in Organic Agriculture

...temperate zone agrotechnology cannot be applied to the tropics; the practice of tropical agriculture is incredibly inept, and whole new concepts based on ecological principles are urgently needed...

Odum, E. P, (1971)

The aim of the green revolution, as justified by its promoters, was to enhance crop production. It is now realised that agriculture does not only refer to crop production but also to various other factors that are responsible for crop production. These had been previously completely overlooked. Factors, such as soil destruction, top soil erosion and the adverse effect of the prolonged use of chemical fertilisers on soil health have been neglected, 'The United States has already lost one-third of its top soil in the last 200 years. Soil erosion in other countries is equally alarming and devastating' (Perlas, 1994). The effects of pesticides on soil and human health have also been ignored. Nearly 25 million farmers in the tropical countries of the world are poisoned every year by chemical pesticides. Chemical agriculture, in the name of conventional agriculture, has affected the basic concepts of agriculture by transforming it into an ugly culture which today has been euphemistically been given the name agribusiness. This has altered the physiological processes of crops, diminished food quality, destroyed soil biota and promoted resistant varieties of insect pests.

In contrast to conventional agriculture, traditional agriculture establishes a religious relationship of the farmer with the earth. In the past, animals were part of the agricultural system and farmers were aware of the benefits of us-

ing their solid and liquid wastes and used this to their advantage. Moreover, crops like *millets, bajra, ragi,* previously used by traditional farmers have been neglected in favour of crops like sunflower and soyabean. The reduced production of coarse cereals has affected fodder production which was used to support farm animals, and also served as mulch to conserve soil moisture and promote rich density and diversity of soil organisms, including earthworms.

Alternate agricultural practices have time and again proved that they are not only resource conserving but also productive. Such viable alternatives include organic farming, ecofarming, biodynamic farming as well as traditional farming practices. These practices work in harmony with nature making use of various indigenously available resources, the chief of them being soil faunal components which establish a synchrony in nutrient cycles.

Vermicompost and/or *in situ* vermiculture associated with other biological inputs have been applied to grow vegetables and other crops successfully. These approaches have proved to be economical as well as productive. The *Organic Farming Sourcebook* (Alvares ed, 1996), identifies several individuals and organisations actively involved in the organic movement as well as the materials and components used for organic agriculture in India.

ARISE (Agricultural Renewal in India for Sustainable Environment) had been a leading umbrella organisation in India working towards sustainable agriculture. ARISE was recognised for its services and was awarded the SARD (Sustainable Agriculture and Rural Development) Prize for Asia at the IFOAM '96 (International Federation of Organic Agricultural Movements) held at Copenhagan during August 1996. The Organic Farming Association of India (2003) is now established in Goa with Claude Alvares as its coordinator.

Collaborative experiments on organic agriculture were carried out with Auroville Greenwork Resource Centre, Auroville at Forecomers Auroville. These experiments had been conducted on brinjal (egg plant), cucumber, okra, tomato, cluster beans, ragi, black gram and groundnut. Biochemical analyses from these experiments reveal relatively higher protein, carbohydrate and lipid content in okra grown on vermicompost, while those harvested from chemical treated plots show a decline in their quality.

Given on the next page are details of some of the experiments carried out in the rural sectors and the economic viability of organic agriculture when compared to chemical cultivation.

Organic method under rainfed conditions

Costs are based on the experiments conducted during 1999-2002. Vermicompost prepared in pits in field conditions using locally available bulking materials has been used for these experiments.

1. Cultivation of peanut (per acre) (All costs in Indian rupees)

COST OF FIELD PREPARATION	
Ploughing of land with country plough twice with 4 ploughs @ Rs.150/plough	600
COST OF COMPOST	
8 tons of FYM as basal dose @ Rs.100/ton	800
2 tons of vermicompost @ Rs.250/ton	500
Cost of transport and labour (2 bullock carts hired @ Rs.200/ cart/day and 2 labourers @ Rs.50/person/day)	500
SEEDS AND SOWING	
Cost of seeds 40 kg/acre @ Rs.30/kg	1200
Seeds sowing with 2 country ploughs @ Rs.200/plough	400
Cost of labour for 2 women @ Rs.25/person/day	50
INTERCULTURAL OPERATIONS	
Weeding by 10 women @ Rs.25/person/day	250
ORGANIC FOLIAR SPRAYS FOR PEST AND DISEASE	
Neem oil or neem cake extract	150
2 litres of Neemosin @ Rs.120/ litre	240
Cost of spraying	150
HARVESTING	
Harvesting by 25 women @ Rs.25/person/day for one day	625
DE-SHELLING	
De-shelling by 10 men @ Rs.50/person/day for one day	500
TRANSPORT COST	250
TOTAL	6,215

Total cost of cultivation of peanut per acre using chemical fertilisers and pesticides (NPK, seed treatment chemicals, gypsum, malathion dusting and endosulphan spraying) = Rs.8,755.

NET PROFIT FROM BOTH TYPES OF CULTIVATION (per acre)

Organic	Rs.7,145.43
Chemical	Rs.5,956.05

(Selling price taken as Rs.15 per kg for both. Organically grown crops, however, fetch a better price in the market.)

II. Cultivation of brinjal (egg plant) (per acre)

COST OF FIELD PREPARATION	
Ploughing of land twice with 4 ploughs @ Rs.150/plough	600
FORMING OF RIDGES AND FURROWS	
Labour charge for 15 persons @ Rs.50/ person /day	750
COST OF COMPOST	
8 tons of FYM as a basal dose @ Rs.100/ton	800
2 tons of vermicompost as a basal application @ Rs.250 /ton	500
Cost of transport and labour (2 bullock carts) hired @ Rs.200/cart/day + 2 labourers @ Rs.50/person/day	500
SEEDS AND SOWING	
Cost of seed 0.5 kg/ac @ Rs.200/kg	100
Cost of field preparation and sowing (area 3 m x 3 m)	50
Cost of compost	20
TRANSPLANTING	
Labour charges for 15 women @ Rs.20/person/day	300
INTERCULTURAL OPERATION	
Labour charges for 10 men @ Rs.50/person/day	500
FOLIAR SPRAY OF NUTRIENTS	
Vermiwash as foliar applicant	100
Biogas slurry filtrate mixed with rock phosphate	100
Spraying cost (twice) @ Rs.100/spray	200
FOLIAR SPRAY OF ORGANICS FOR PESTS AND DISEASES	
Neem oil or neem cake extract	150
2 litres of Neemosin @ Rs.120/litre	240
COST OF IRRIGATION	
Irrigation cost @ Rs.15/hour	1500
COST OF HARVESTING	
Labour charges for 3 women + 1 man @ Rs.20 and Rs.50/person/day respectively for 30 days	3300
OVERALL TRANSPORT COST	500
TOTAL	10,210

Total cost of cultivation of brinjal per acre using chemical fertilisers and pesticides (NPK complex, urea and phosphate; foliar sprays; hormones; BHC and endosulphan) was Rs.11,465

NET PROFITS FROM BOTH TYPES OF CULTIVATION (per acre)

Organic	Rs 18,290.50
Chemical	Rs.17,762.25

(Selling price taken as Rs.4 per kg for organically grown and Rs.3 per kg for chemically grown vegetables.)

III. Cultivation of okra (per acre)

COST OF FIELD PREPARATION	
Ploughing of land with country plough twice with 4 ploughs @ Rs.150/plough	600
FORMING OF RIDGES AND FURROWS	
Labour charge for 15 persons @ Rs.50/ person /day	750
COST OF COMPOST	
8 tons of FYM as a basal dose @ Rs.100/ton	800
2 tons of vermicompost @ Rs.250 /ton	500
Cost of transport and labour (2 bullock carts) @ Rs.200/cart/day + 2 labourers @ Rs.50/person/day	500
SEEDS AND SOWING	
Cost of seed 6 kg/ha @ Rs.100/kg	600
Cost of field preparation and sowing (area 3 m x 3 m)	50
Labour charges for 15 persons @ Rs.20/person/day	300
INTERCULTURAL OPERATION	
Gap filling by 3 persons @ Rs.20/person/day	60
Weeding by 10 persons @ Rs.50/person/day	500
FOLIAR SPRAY OF NUTRIENTS	
Vermiwash as foliar applicant, biogas slurry filtrate mixed with rock phosphate	100
Spraying cost (twice) @ Rs.100/spray	200
FOLIAR SPRAY OF ORGANICS FOR PESTS AND DISEASES	
Neem oil or neem cake extract	150
2 litres of Neemosin @ Rs.120/litre	240
COST OF IRRIGATION	
Irrigation cost @ Rs.15/hour	1125
COST OF HARVESTING	
Labour charges for 2 women and 1 man @ Rs.20 and Rs.50/person/day respectively for 30 days	2200
OVERALL TRANSPORT COST	500
TOTAL	9,175

Total cost of cultivation of okra per acre using chemical fertilisers and pesticides (NPK complex; urea and phosphate; foliar sprays; hormones; BHC and endosulphan) was Rs.10,844

NET PROFIT FROM CULTIVATION

Organic	Rs.6,803.75
Chemical	Rs.6,931.00

(Selling price taken as Rs.4.50 per kg for organically grown and Rs.4 per kg for chemically grown vegetables.)

IV. Cultivation of paddy

Rice and sugarcane are two essential commercial crops of India. Rice especially has been cultivated based on seasonal rhythms in tune with rice varieties and with an essential rotation of crops following the paddy-groundnut-paddy system, FYM (farm yard manure) serving as the chief input. The impact of the green revolution has interfered with the precious role of microbes in the nutrient cycling process by direct pumping of chemical fertilisers into the soil causing destruction of both soil fauna, and the synchrony in nutrient cycles. Vermicompost alone not may be sufficient to support paddy (Plate 11). A package of fertilisers of biological origin is recommended as shown below in which vermicompost forms an important constituent.

Table 12: Recommended fertiliser and pesticide application to be carried out after transplantation of paddy seedlings in organic packages compared to the conventional chemical package and biometrics of paddy (Crop: ADT 36; plot size: 3 cents; duration of crop: 108 days)

Operation	Organic	Chemical
Green manures ploughed in on 45th day and main field prepared	Sesbania rostrata at the seed rate of 8 kg/acre	Nil
Basal dose	Farm Yard Manure (FYM) 187.50 kg	Urea 0.525 kg Super phosphate 4.5 kg Murate of potash 0.75kg
8th day after transplanting	Azolla microphylla 12 kg	Nil
1st top dressing	Vermicompost 30 kg Neem cake 0.75 kg	Urea 0.525 kg
2nd top dressing	Vermicompost 30 kg	Murate of potash 4.5 kg
3rd top dressing	Vermicompost 60 kg	
Pesticide	Nil	Monocrotophos 2 sprays @ 50 ml each
Number of tillers	12.01 ± 1.30	13.50 ± 4.01
Height (cm)	72.40 ± 2.56	72.10 ± 6.20
Number of panicles per hill	11.40 ± 2.36	10.40 ± 2.53
Length of panicles (cm)	22.30 ± 1.33	21.15 ±1.92
Number of grains per panicle	100.35 ± 15.55	113.10 ± 26.5
Number of chaffs	13.78 ± 4.83	12.60 ± 8.40
Weight of 1000 grains (g)	19.91	19.45
Grains (kg/acre)	688.33	687.50
Straw (kg/acre)	1209.00	1110.50

V. Cultivation of sugarcane

India has one of the highest cane acreage among cane growing countries in the world. Though chemicals are today preferred as inputs for cane growing, organics such as FYM, pressmud, bagasse, molasses, green manure, compost and oil cakes were the earlier inputs for sugarcane cultivation. Vermicompost made through vermitech was used as a sole input for sugarcane cultivation. Paddy and sugarcane cultivation was done in collaboration with M S. Swaminathan Research Foundation at Pillayarkupparn, Pondicherry. The results are highly encouraging as illustrated in the table 13.

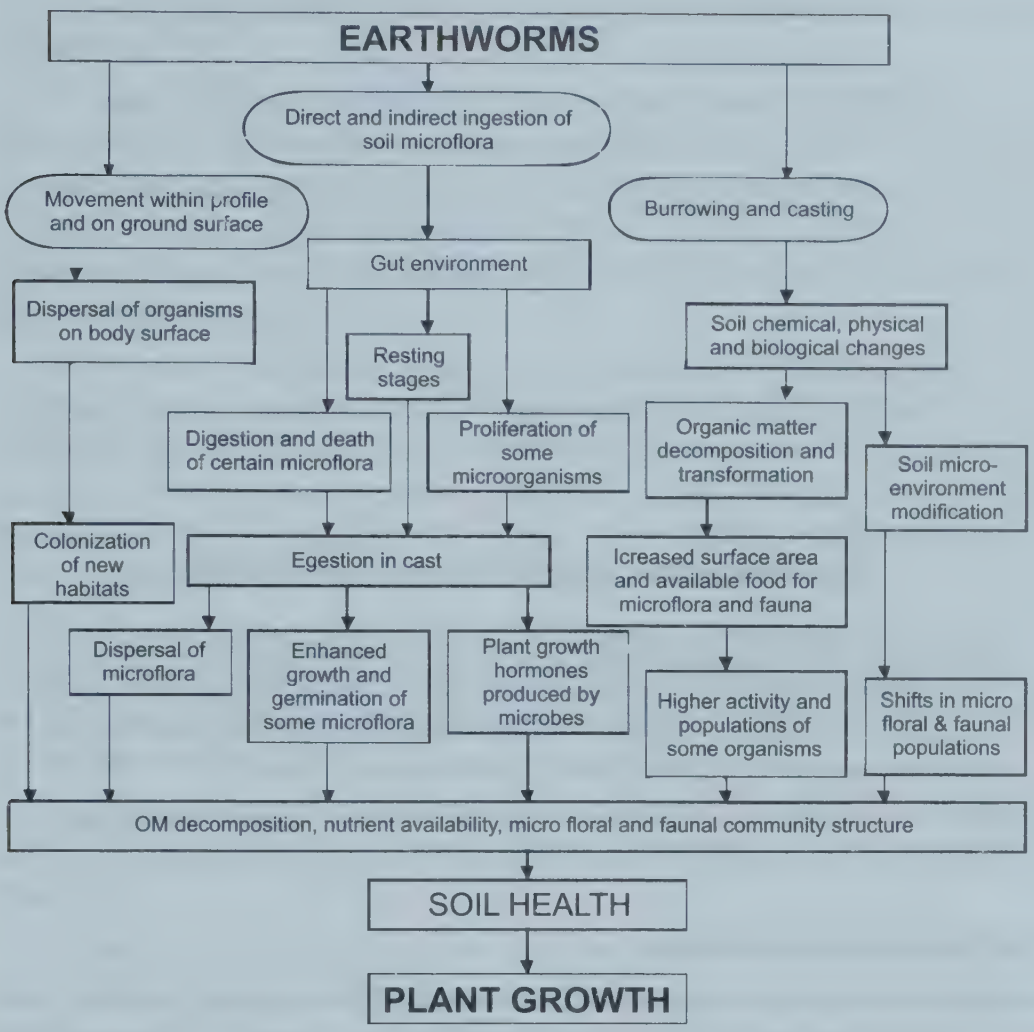
Table 13: Biometrics of sugarcane (var. Coc 90063), yield and cane quality

Parameters	Chemical	Vermicompost
BIOMETRICS	Mean ± S.E	Mean ± S.E
Millable canes /hill	6.00 ± 0.81	6.66 ± 0.98
Internode distance (cm)	10.80 ± 0.60	11.66 ± 0.49
Cane thickness (cm)	3.26 ± 0.11	3.05 ± 0.02
Total cane length (m) (Shoot + stem only)	4.40 ± 0.21	3.88 ± 0.39
YIELD (tons /ha)	133.38	141.36
CANE QUALITY		
% Brix	15.05	17.17
% PoI	12.22	14.66
% Purity	81.20	85.38
Commercial cane sugar	8.32	10.24

Using organic inputs also improves the soil faunal diversity and density. Anecic earthworms are found during the harvesting of paddy and sugarcane. These are indicators of soil health.

The effects of earthworms on soil microflora leading to changes in soil properties, processes, micro-floral and faunal community structure, and plant and soil health can be illustrated through a schematic diagram (Dhakshayani, *et al.*, 2003) (see page diagram on pg.75).

Vermicompost and vermiwash, along with other organic inputs like coir pith compost, pressmud, FYM and burnt rice husk have been successfully used in the initial setting of turfs and soil amelioration for the Sporting Pastime India Limited at Cheyyur, in Tamil Nadu along with neemcake, neem oil, extracts from plants like *Vitex negundo and Pongamia glabra* diluted with cow's urine and vermiwash as pest repellants.


EARTHWORMS
Direct and indirect ingestion of soil microflora
Movement within profile and on ground surface
Burrowing and casting
Gut environment
Dispersal of organisms on body surface
Resting stages
Soil chemical, physical and biological changes
Digestion and death of certain microflora
Proliferation of some microorganisms
Organic matter decomposition and transformation
Soil micro-environment modification
Colonization of new habitats
Egestion in cast
Icreased surface area and available food for microflora and fauna
Dispersal of microflora
Enhanced growth and germination of some microflora
Plant growth hormones produced by microbes
Higher activity and populations of some organisms
Shifts in micro floral & faunal populations
OM decomposition, nutrient availability, micro floral and faunal community structure
SOIL HEALTH
PLANT GROWTH

Earthworms, vermicompost and vermiwash, thus, are inseparably interrelated and they interact with organic agriculture for an ecofriendly existence and a sustainable environment. Healthy soils have a rich density and diversity of soil fauna, particularly earthworms, and such healthy soils support healthy plants with an inbuilt resistance to pest attack and diseases.

In conclusion, let us remember Perlas's (1994) words: 'Do we grow our crops with genetically engineered resistance to polluting herbicides or do we develop ecological forms of agriculture which work with the rhythms and cycles of nature to achieve the same end of feeding humanity?'

IX

Earthworms: End Uses and Potential

It is now accepted that the economic value of vermiculture lies in (i) diminution of noxious qualities associated with organic wastes, e.g. elimination of smell; (ii) generation of a useful compost; and (iii) production of earthworm biomass as a source of food, primarily proteins, and of drugs.

Sabine, J. R., (1983)

Earthworms in medicine

Folk tales dating from at least as far back as AD 1340 abound with stories of the medicinal value of earthworms, covering a range of diseases from pyorrhoea to post-partal weakness, from small pox to jaundice, to rheumatism (Reynolds and Reynolds, 1972).

The Unani system of medicine classifies earthworm as *Kharateen.* According to Vohora and Khan (1978), *Kharateen* in the *Unani* system, is used both internally and externally as a powerful aphrodisiac. Besides this, they have also reported the role of earthworms in the healing of wounds, chronic boils, piles and sore throat.

Hamdullah Mustanfi of Qazwin in the *Nuzhatul Qulub,* a scientific encyclopaedia written in AD 1340, (cf-Stephenson, 1930), tells us that earthworms baked and eaten with bread reduce the size of stones in the bladder and bring about its expulsion and, when earthworms are dried and eaten they cure the yellowness of jaundiced patients. In difficult labour they are reported to bring about delivery immediately.

Hori *et al.,*(1974) have reported significant antipyretic activity derived from the earthworms, *Lumbricus spencer* and *Perichaeta communisima,*

after testing them on rabbits induced with fever by injecting pyrogen from *Escherichia coli.*

Because of its antipyretic properties earthworms are reportedly used in China and Japan in the dry form for reducing fever. Earthworms have also been used for testing pregnancy in human females (Hasenbein, 1951). For this test, urine from females is injected into earthworms subcutaneously. Smears are taken from their seminal vesicles, both before and after injection, to assess spermatogenesis.

Earthworms have been used to treat smallpox in Myanmar and Laos (Bristowf, 1932). Dried worms are reportedly mixed with almond oil and applied on the affected areas in cases of hernia. They were also supposed to have been useful for curing chronic cough, diphtheria, jaundice and also for facilitating delivery (Hussain, 1771; Khan, 1911; Shukla, 1950; Kabiruddin, 1955; Anonymous, 1959; Wahid and Siddiqui, 1961).

Earthworms, when ingested into the system, increase body heat and are of value in nervine disorders, bronchitis and tuberculosis. Weisbach (1962), has also reported that earthworms might contain a substance effective in curing rheumatism.

Their potential in family planning is noteworthy as they show spermatocidal properties (Zang *et al.,* 1992). The characteristics of its spermatocidal effects are:

(i) rapidly halting the movement of spermatozoa; and

(ii)driving the spermatozoa into clumps or bunches, resulting in specific agglutination .

Besides these pharmacological contributions, earthworms also have the potential of being used as antiinflammatory and fibrinolytic drugs. The antiinflammatory activity of total earthworm paste (TEP) was studied in carrageenan induced oedema and cotton pellet granuloma in rats (Yegnanarayan *et al.,* 1987, 1988). It was found that the efficiency was similar to that of aspirin on carrageenan induced oedema (Ismail *et al.,* 1992).

Mihara *et al.*, (1991 a, b) in *Lumbricus rubellus* and Akthar *et al.*, (observations) in *L. mauritii* have reported earthworms to be potentially very useful for treating thrombosis and infact, find that orally administered earthworm powder is capable of digesting intravascular fibrin clots.

The day is not far away when people probably may say an earthworm a day will keep the doctor away!

Earthworms as feed

Apart from earthworms being used in composting, maintenance of soil fertility and preparation of drugs, they could also be consumed as food (Sabine, 1983) either by domestic animals or by human beings.

The high protein content (58–71% dry weight basis) of earthworms could be utilised in intensive pig and poultry farms. The actual nutritive value of a feed protein, however, depends upon its specific amino acid composition. Earthworm protein is high in essential amino acids, including those containing sulphur (table 14).

Table 14: Amino acid composition of earthworm protein (g per 100 g of protein) (Source Taboga, 1980)

Ala	5.4	Met*	2.0
Arg*	7.3	Phe*	5.1
Asp	10.5	Pro	5.3
Cys	1.8	Ser	5.8
Glu	13.2	Thr*	6.0
Gly	4.3	Try*	2.1
His*	3.8	Tyr	4.6
Ile*	5.3	Val*	4.4
Leu*	6.2		
Lys*	7.3	(*Essential amino acids)	

Apart from amino acids the presence of specific nutritive compounds in earthworm tissues include triglycerides (Hansen and Czochanska, 1974), squalene (Voogt *et al.*, 1975) and free fatty acids (Naya and Kotake, 1967).

Earthworm meal has been experimentally fed to chickens (Mekada *et al.*, 1979; Yoshida and Hoshii, 1978; and Taboga, 1980) and pigs (Harwood and Sabine, 1978). Experiments have also been conducted by feeding earthworm meal to mice and rats (McInroy, 1971; Schulz and Graff, 1977). In all these trials, the results have consistently indicated that animals fed on earthworm meal as the major source of protein in their diets have all grown at rates equal to or better than those displayed by animals fed with conventional protein meals. According to Harwood (1976) and Mekada *et al.*, (1979) chickens fed on earthworm meal had better feed conversion ratios.

Worm meal is likely to be a component in commercial fish feed and may soon be considered a delicacy for the human palate as well.

A note of caution however is necessary since earthworms are capable of accumulating toxic residues particularly of metals and agrochemicals. They

late lead, cadmium, chromium, copper, nickel, mercury and zinc (Gish and Christensen, 1973; Hartenstein *et al.,* 1980a; Beyer, 1981, Ireland, 1983 and Joseph *et al.,* 1992). They seem to tolerate large concentrations of such metals in their tissues and continuous monitoring is essential if earthworms are introduced in large quantities into the preparation of worm meals. A similar monitoring has to be maintained to assess the concentrations of agrochemicals (fertilisers and biocides) which would demand extensive quality checks of meals derived from worms grown on agrowastes and animal manures.

Before introducing earthworm feed in poultry and aquaculture as an appropriate technology, several laboratory and field trials must be carried out and the cost benefit analysis and sociological aspects of acceptability must be considered (Kale, 1986).

Economic potential

The economic viability of earthworm production depends upon the rate and cost of production and the price available for the product. A rate of protein production of about 6500 kg ha^{-1} yr^{-1} should be attainable. But most of these observations are based on an extrapolation of data from small laboratory-scale tests (Hartenstein, 1981).

Legal constraints

Many food laws distinguish between an 'ingredient' and an 'additive' with different regulations and restrictions applying to each. Earthworm growers should concentrate, at least initially, on classifying of their product as a regular high protein ingredient (Sabine, 1983).

Conclusion

The pace at which soil degradation has taken place since the green revolution is apparent and, today, there are no divided opinions about the need of restoring soil health. The simultaneous awareness in the minds of the human population on the dangerous effects of chemical residues due to large scale application of biocides, and the subsequent demand for food grown on organic fertilisers has made farmers and agriculturalists think about the validity of mass scale application of chemicals in agriculture. Large scale poaching of common property resources and mismanagement of watersheds have already depleted nutrient inputs.

Several organic alternatives from the traditional farming practices in India are being suggested today. Organic farming packages could be designed by integrating green manures, FYM (farmyard manure), vermicompost, vermiculture and *in situ* earthworm management. Soil faunal and soil organic matter components, biodynamic farming components and Ecological Pest Management (EPM) could be encouraged. Many farmers in India and abroad

are now aware of the contributions made by earthworms towards encouraging soil faunal diversity and promoting soil health. To achieve this, farmers have to look for the worms just beneath their feet as there are no earthworms in this world superior to earthworms found in their own soil. A little awareness of vermiculture could help him add the right nutrient resources and optimum amount of water which would multiply the local worms manifold *in situ* in fields where these earthworms begin their immediate action as nature's ploughs and fertiliser units.

Large scale vermiculture operations, however, produce two saleable products, earthworms and vermicompost. The economic viability of any vermiculture system, at least for a long time to come, will probably depend upon the financial return from compost production rather than from worm protein (Sabine, 1983).

The future

It is possible to predict a bright future with vermicastings and vermicompost. *In situ* vermiculture and vermi management with properly prepared vermibeds will provide vermi communities of vermi density and vermi diversity which in turn will lead to vermi soil fertility.

Epilogue

Nature has bestowed every soil type with its own native flora and fauna. Earthworms, as true soil dwellers, are qualitatively and quantitatively distinct and different in each type of soil. During the past 25 years of my research pertaining to the study of the bioecology of earthworms, I have distinctly observed a rich diversity of earthworm species in different soils of our country. Among them, *L. mauritii* is one of the outstanding species of earthworms which distinguishes itself in the biodegradation of organic solid wastes and also in the amelioration of poor soils by improving soil quality. This worm accepts a wide range of soils and conditions and I am perplexed to observe that *L. mauritii* accepts not only sands with organic amendments but also highly alkaline sodic soils [in preliminary experiments of reclaiming highly alkaline sodic soils using earthworms for the Uttar Pradesh Land Development Corporation, Lucknow (India)]. Its wide acceptance as a biological phenomena, its potential to exhibit bioluminescence as well as its therapeutic properties has always made me admire the earthworm *L. mauritii* as a wonder worm as compared to all other earthworms.

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Glossary

Azolla: freshwater fern with specialised leaf cavities inhabited by the blue-green algae *Anabaena azolla* which are photosynthetic nitrogen fixing organisms. Used as a biofertiliser in paddy cultivation

Azotobacter: a genus of soil bacteria which helps in nitrogen fixing

Black Box: this is significant because just as every minute detail of the functioning of an aircraft is recorded in the Black Box the flight data recorder similarly, Nature functions through every minute detail of the ecosystem and to select or reject a few features in an ecosystem is a merological (mero=half or part) approach, while the Black Box approach is hololological (holo=total or whole)

bioluminescence: the emission of visible light by some living organisms

community: an organised unit consisting of an assembly of populations of organisms living in a prescribed area of physical habitat

FYM: Farm Yard Manure. It is made up of three types of substances dung, urine of animals and straw or other plant refuse (agrowaste)

geophytophagous: organisms which feed on the leaf litter mixed with the soil of the upper horizons

green manures: green manuring is an alternative to using of nitrogen from chemical fertilisers for the satisfactory maintenance of soil organic matter. It is the practice of incorporating specifically grown plants into the soil such as the leguminous shrub, *Sesbania* sp, for use as green manure

Panjakavia: a potion prepared with cow's urine, dung, milk, curd and ghee amended with ripe banana, sugarcane juice and tender coconut water; and fermented.

parthenogenesis: a special type of reproduction in which ova develop without fertilisation by sperm

pedogenesis: the formation and development of soil

phytophagous: organisms which feed on leaf litter and other decaying matter

saprophages: organisms which disintergrate organic products by consuming them

synchrony: the release of nutrients from aboveground inputs synchronised with plant growth demands thorough control of soil management and input quality

VAM: Vesicular Arbascular Mycorrhizae are fungi which establish beneficial association with roots of growing crops and in the process increase the growth of associated plants

VEMP: Vermicompost-Earthworm-Mulch-Plant root interactions

Vermibed. A term coined by Ismail. This comprises a layer of 15–20 cm thick loamy soil above a thin, 3 cm layer of broken bricks and coarse sand. Earthworms are introduced in the soil layer with little cattle dung and hay on the top as feed. The earthworms grow and multiply in this bed

vermicastings: these are the excreta of earthworms, the nutrient status of which is higher than the surrounding soil

vermiculture: this is the culture of earthworms

vermitech: a term coined by Ismail for the technology of using local species of earthworms for culture or composting of organic debris/garbage and other related practices as developed by Ismail and his team (a worm powered technology).

vermiwash: a liquid fertiliser collected after the passage of water through a column of worm activation. It is very useful as a foliar spray

windrow: organic wastes piled in elongated rows.

Plate 1: *Perionyx excavatus*

Plate 2: *Lampito mauritii*

Plate 3: *Octochaetona thurstoni*

Plate 4: *Octochaetona serrata*

Plate 5: Cocoons of earthworms (from top left clockwise) (pin: 25 mm)

- *Drawida modesta*
- *Lampito mauritii*
- *Octochaetona thurstoni*
- *Octochaetona serrata*
- *Perionyx excavatus*

Plate 6: Different stages in the cocoons of *Lampito mauritii* (from top left clockwise) (pin: 25 mm)

- Freshly laid cocoons
- Brown, with incubation
- Deep brown about to hatch
- Young earthworm coming out of the cocoon
- An empty case

Plate 7: Cocoons of *Lampito mauritii* (pin: 25 mm)

Plate 8: Tuft-like projections in the cocoons of *Perionyx excavatus* (pin: 25 mm)

Plate 9: Earthworms activity resulting in 'worm-worked' sodic soils (Experiment for UPLDC, Lucknow, India)

Plate 10: Compost ready for harvest

Plate 11: Growing paddy on vermicompost

Plate 12: Growing sugarcane on vermicompost

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Dr Sultan Ahmed Ismail's *The Earthworm Book* contains practical information about the place of earthworms in local ecosystems, the various types of earthworms present in the soil, their anatomy, the economics of composting and vermiwash production and the application of these in organic farming from vegetables to crops.

Dr Ismail also provides invaluable and practical information about how to set up vermiculture, vermicomposting and vermiwash units.

Throughout the book, Dr Ismail stresses the importance of working with nature and describes the hazards of disturbing the ecosystem in the name of biotechnology and advanced farming practices. He also firmly advocates use of local earthworms in preference to exotic species.

Although the book is serious in its intent, the language used is fairly simple and scientific terminology has been kept at a level that can be easily understood by the lay reader.

About the Author: Dr Sultan Ahmed Ismail is India's leading authority on earthworms. He is former Director of Eco Science Research Foundation, Chennai. He is presently Member of State Planning Commission and Panel to frame the State Education Policy, Government of Tamil Nadu and more recently nominated as President of the Gandhi Ashram, Thiruchengode. *The Earthworm Book* has been *translated* in Tamil, Chinese and Persian.

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